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Emergency Response
Washington, DC 20460

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October 1991

EPA

Innovative Treatment Technologies

Overview and Guide to Information Sources

EPA/540/9-91/002
October 1991

INNOVATIVE TREATMENT TECHNOLOGIES: OVERVIEW AND GUIDE TO INFORMATION SOURCES

Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, D.C. 20460

October 1991

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NOTICE

The preparation of this guide has been funded by the U.S. Environmental Protection Agency. It has been subject to the Agency's review and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

FOREWORD

This document was originally prepared by the U.S. Environmental Protection Agency (EPA) Technology Innovation Office to support a training module on innovative treatment technologies which was presented at the On Scene Coordinator (OSC)/Remedial Project Manager (RPM) Training Academy. It represents an effort to gather, under one cover, a wide variety of existing technical guidance and information that describes the status and capabilities of selected technologies.

EPA recognizes that the manual is not comprehensive; some technologies were omitted due largely to practical considerations. For example, solidification/stabilization technologies were not included in this version of the guide and may be included in future update. Although incineration technologies are established technologies by the definition used in this manual, they are included to provide the user with a benchmark for evaluating innovative treatment technologies. A revised and expanded version of this document may be prepared in the future, based on comments we receive.

This document is intended as a reference guide to assist site project managers, consulting engineers, responsible parties, and owner/operators in their efforts to identify current literature on innovative treatment technologies and to support the overall decision making process for hazardous waste site remediation or corrective action.

Walter W. Kovalick, Jr., Ph.D.
Director, Technology Innovation Office

ABSTRACT

This document is a compilation of information on innovative treatment technologies now being used in the Superfund program. It provides a broad overview of innovative treatment technologies to assist site managers in their initial evaluation of innovative treatment technologies. The material is focussed on a limited number of technologies, primarily those that treat organic contamination. The technologies discussed include:

- Incineration
- Thermal Desorption
- Soil Washing
- Solvent Extraction
- Dechlorination
- Bioremediation
- Vacuum Extraction
- In situ Vitrification
- Ground Water Treatment

For each category of treatment, the document provides a brief description of the physical, chemical, and biological processes used by the technologies in that category. Summaries of the status, applications, strengths, and weaknesses of the technologies follow the descriptions. Where the information is available, the document includes facts on the characteristics of the waste or sites that may affect the performance of the technology. Also included, where available, are overview reference materials such as technical bulletins, journal articles, engineering references and a list and summary of information on remedial and removal sites where these technologies have been selected. The contacts who are listed as responsible for these sites are EPA, State, and contractor personnel who have experience with issues related to the application of these technologies at specific sites.

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Note: More detailed table of contents may be found at the beginning of each section.

EXHIBIT 2 - EMERGENCY RESPONSES: SUMMARY OF INNOVATIVE TECHNOLOGIES USED FOR SOURCE CONTROL

Abbreviations

APC	air pollution control
APEG	alkaline metal hydroxide/polyethylene glycol
ATEG	alkaline metal hydroxide/tetraethylene glycol
ATTIC	alternative treatment technology information center
BCD	base catalyzed decomposition
BEST	basic extractive sludge treatment
BOD	biological oxygen demand
BTEX	benzene, toluene, ethlybenzene, xylene
BTU	british thermal units
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm/s	centimeters per second
COD	chemical oxygen demand
cy	cubic yard
DCA	dichloroethane
DCE	dichloroethene
DOE	Department of Energy
DRE	destruction and removal efficiency
EPA	Environmental Protection Agency
FY	fiscal year
ISV	in situ vitrification
KPEG	potassium hydroxide/polyethylene glycol
Kw-hr/yd^3	kilowatt hours per cubic yard
NAPL	nonaqueous phase liquids
NCP	National Contingency Plan
NPL	National Priorities List
ORD	Office of Research and Development
OSC	on scene coordinator
OSWER	Office of Solid Waste and Emergency Response
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	perchloroethylene
PCP	pentachlorophenol
PIC	product of incomplete combustion
ppb	parts per billion
ppm	parts per million
PRP	potentially responsible party
RCRA	Resource Conservation and Recovery Act
ROD	Record of decision
RPM	remedial project manager
RSKERL	Robert S. Kerr Environmental Research Laboratory, Ada, OK (U.S. EPA)
SARA	Superfund Amendments and Reauthorization Act
SITE	Superfund Innovative Technology Evaluation program
START	Superfund Technical Assistance Response Team
SVOC	semivolatile organic compounds
TCA	trichloroethane
TCE	trichloroethylene
TEA	triethylamine
TIO	Technology Innovation Office
TOC	total organic carbon
USATHAMA	United States Army Toxics and Hazardous Materials Agency
USGS	United States Geological Survey
UST	underground storage tanks
VOC	volatile organic compound

Acknowledgements

This report was prepared under the direction of John Kingscott and John Quander of the Technology Innovation Office. The guide was compiled by PRC EMI under Contract No. 68-W0-0034.

The authors would like to acknowledge the technical contributions of Dave Pepson and Nancy Willis of PRC. Deborah Lyne of PRC deserves special recognition for her efforts to organize, compile, and revise this document. The authors would also like to thank our peer reviewers and authors of the papers used in the document, especially those prepared by EPA's Ada, OK and Cincinnati, OH Office of Research and Development Laboratories.

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1.0 INTRODUCTION

BACKGROUND

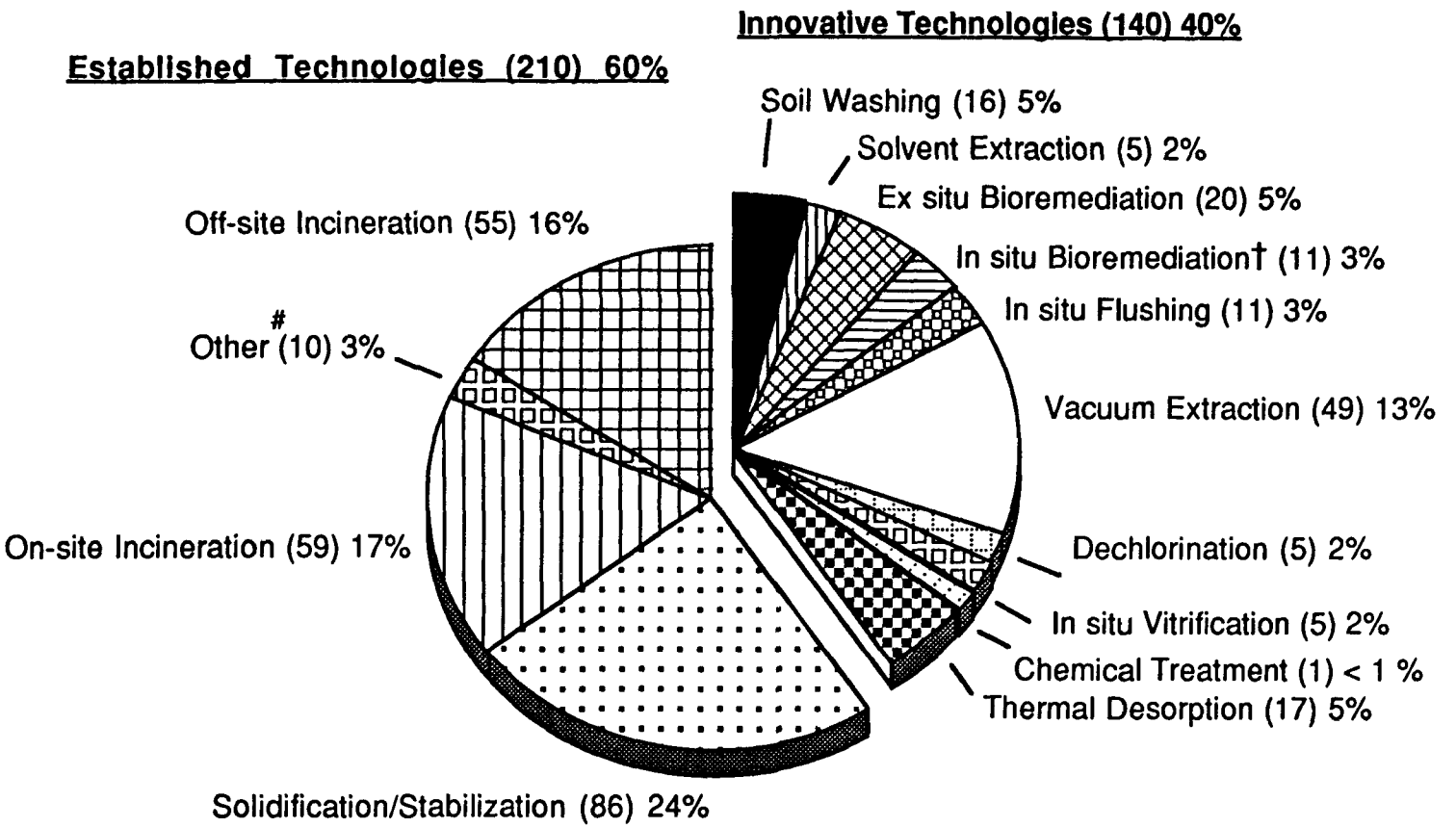
With the passage of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or Superfund, Congress made a commitment to protecting human health and the environment from uncontrolled hazardous wastes. At that time, the nation was just beginning to understand the scope and complexity of this challenge. The number of national priority sites now exceeds 1,200, and the number of uncontrolled sites that may need to be addressed by state and federal programs may range from 130,000 to 425,000, as estimated by the U.S. General Accounting Office.

In the early years of the Superfund program, the primary method for handling hazardous waste was land disposal, which can be cost effective in the short run but can create greater long-term problems and costs. When CERCLA was amended in 1986 by the Superfund Amendments and Reauthorization Act (SARA), an emphasis was placed on achieving long-term effectiveness and permanence of remedies at Superfund sites. The revised National Oil and Hazardous Substances Pollution Contingency Plan promulgated in March 1990, provides a regulatory framework for implementing this concept and emphasizes the use of "permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable."

The universe of Superfund sites comprises a broad array of physical, chemical, and environmental conditions that need varying types of remediation. Cleanup efforts are no longer dominated by a few technologies; rather, a growing number of innovative technologies are being explored by state and Federal agencies, and private parties. Exhibits 1 and 2 portray the extent to which some of these technologies are planned for use as remedial source controls (Exhibit 1) and emergency response actions (Exhibit 2) at Superfund sites. The use of innovative technologies offers the potential for cost-effective, long-term solutions to hazardous waste cleanup and may be the key to implementing both the CERCLA and Resource Conservation and Recovery Act (RCRA) programs successfully.

The U.S. Environmental Protection Agency (EPA) has taken initiatives in policy, technical, and informational arenas to foster the exploration and application of new remediation techniques. A summary of some of these is provided in Exhibit 3. In addition, EPA has established the Technology Innovation Office (TIO), whose primary goals are (1) to develop a strategy for addressing the regulatory, institutional, and informational impediments that constrain

Remedial Actions: Summary of Alternative Treatment Technologies Through Fiscal Year 1990*



* Data are derived from 1982 – 1990 Records of Decision (RODs) and anticipated design and construction activities as of August 1991. The 350 technologies are associated with 301 sites; the difference reflects the use of more than one technology per site.

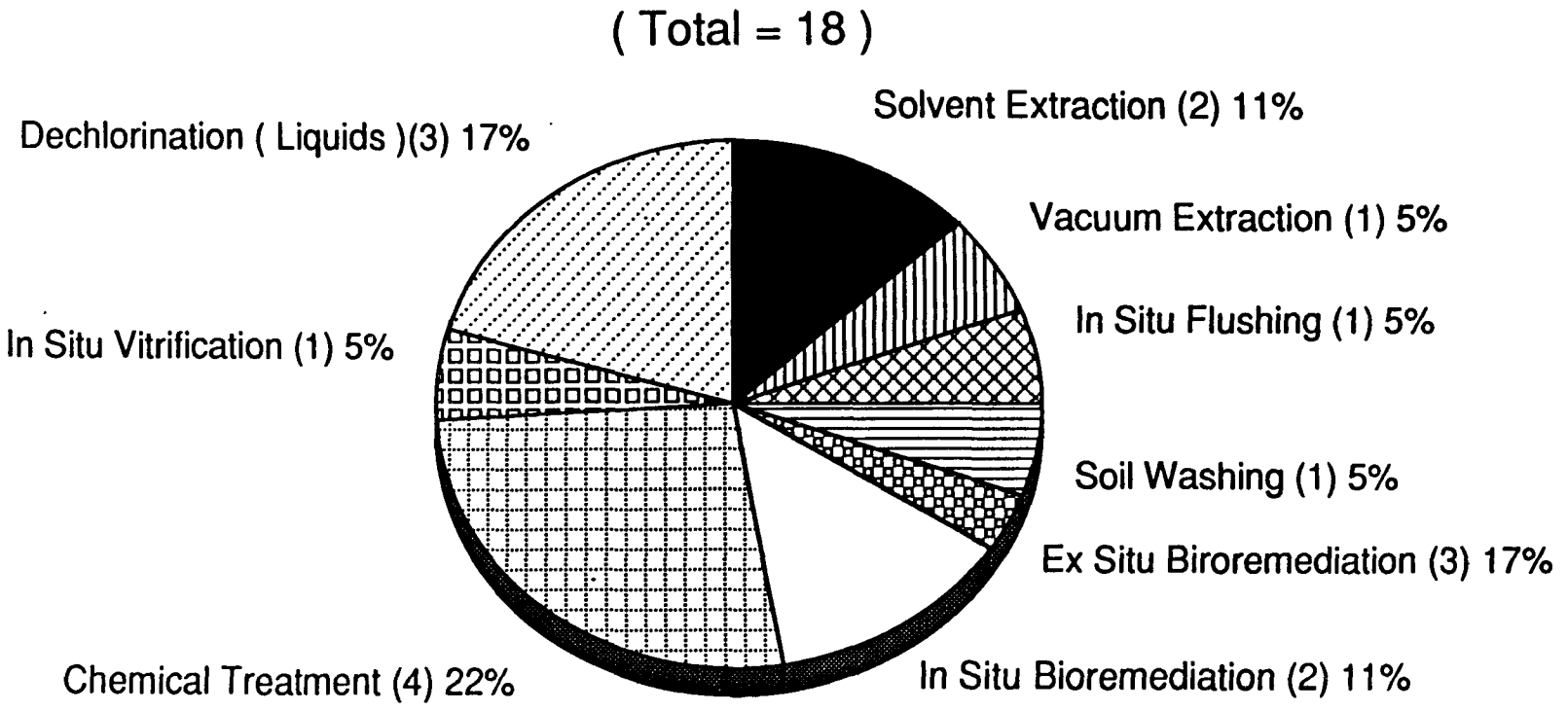
( ) Number of times this technology was selected or used.

"Other" technologies are soil aeration, in situ flaming, and chemical neutralization.

† Includes in situ groundwater treatment.

September 13, 1991

Emergency Responses: Summary of Innovative Technologies Used for Source Control*



* Data from the Removal Tracking System, CERCLIS, and phone survey of regional TAT offices. Includes two projects from FY 91 as of August 1991.

( ) Number of times this technology was selected or used.

Policy

SARA/NCP

Superfund Management Review (90-Day Study)

Use of Treatment Technologies for Superfund Remedies
(OSWER Directive No. 9355.0-26)

Furthering the Use of Innovative Treatment Technologies in OSWER Programs*
(OSWER Directive No. 9380.0-17 FS)

Information Management

Bibliographies *

ATTIC; Hazardous Waste Collection *

Treatment Vendor Directory (planned) *

Market Assessment (planned) *

Program Exhibit for Major National/International Conferences

Innovative Treatment Technologies: Semi-Annual Status Report

Technical

SITE Program *

START Program

Bioremediation Field Initiative

Treatability Study Initiative*

Engineering Forums

Other ORD Programs
- Small Business Innovative Research Grants
- Base Research Programs
- Hazardous Substance Research Centers

* See appendices to this manual for further information on these items.

the use of new technologies and (2) to work closely with Agency and state staff, private parties, and commercial vendors in implementing this strategy.

PURPOSE

This document has been prepared by TIO for use in training sessions and seminars with On Scene Coordinators (OSCs), Regional Project Managers (RPMs), and state project managers. The document contains summary information on selected technologies to assist site managers in their initial evaluation of innovative treatment technologies. In this focussed effort, the material was selected to provide information on a limited number of innovative treatment technologies with particular emphasis on those technologies that are applicable to organic contamination. It is not intended or planned to be an exhaustive review of innovative treatment technologies nor is it intended to be a complete reference on any one technology.

This document is primarily intended to provide site managers with a broad overview of innovative treatment technologies and several categories of treatment have not been included. Most notably, the manual does not provide information on technologies to immobilize contaminants (solidification/stabilization) and flush contaminants from the soil in place (in situ soil flushing). Although the focus of the document is source control, a chapter is included for ground water remediation. Based on comments from users of the document and future developments in technology, summaries of these and other technologies may be added in future editions of the document.

The document provides information on several types of technology organized into nine categories of hazardous waste treatment, as follows:

1. **INCINERATION**
   - Rotary kiln
   - Infrared
   - Circulating fluidized bed
2. **THERMAL DESORPTION**
   - Directly heated desorbers
   - Indirectly heated desorbers
   - In situ steam extraction
3. **SOIL WASHING**
4. **SOLVENT EXTRACTION**
5. **DECHLORINATION**

6. **BIOREMEDIATION**
   - Slurry phase bioremediation
   - Contained solid phase bioremediation
   - Land treatment
   - In situ

7. **VACUUM EXTRACTION**

8. **IN SITU VITRIFICATION**

9. **GROUND WATER TREATMENT**
   - Pump and treat
   - In situ treatment

For each category of treatment, this document provides a brief description of the physical, chemical, and biological processes used by the technologies in that category. Summaries of the status, applications, strengths, and weaknesses of the technologies follow the descriptions. Where the information is available, the document includes facts on the characteristics of the waste or site that may affect the performance of the technology. Also included, where available, are overview reference materials such as technical bulletins, journal articles, engineering references, and a list and summary of Records of Decision (RODs) for sites where the technology has been selected. The contacts who are listed as responsible for these sites are EPA, State, and contractor personnel who have experience with issues related to the application of these technologies at specific sites.

The innovative treatment technologies discussed in this guide may be used with traditional or other innovative technologies in treatment "trains." Technologies may be combined to separate the contaminated material prior to further treatment or to address multiple contaminants within the medium. Several innovative technologies provide separation or pre-processing prior to detoxification of the hazardous constituents. Based on the RODs signed from 1982 to 1990, the remedies selected at sites included combinations of the innovative technologies described in this guide. These sites are:

Resolve, MA	-	Thermal desorption followed by dechlorination
Pinette's Salvage Yard, ME	-	Solvent extraction and incineration
Ewan Property, NJ	-	Soil washing and solvent extraction
Myers Property, NJ	-	Dechlorination and soil washing
Wide Beach, NY	-	Thermal desorption followed by dechlorination
American Creosote Works, FL	-	Soil washing and bioremediation
Coleman Evans Wood, Preserving, FL	-	Soil washing and bioremediation

Cabot/Koppers, FL	-	Soil washing and bioremediation
Jadco Hughes, NC	-	Vacuum extraction followed by in situ flushing
Moss American, WI	-	Soil washing followed by bioremediation
Sand Creek, CO	-	Soil washing followed by incineration

DEFINITIONS

In reading this manual, it will be helpful to understand several key terms. The phrase "alternative technology" was originally derived from the concept of an alternative to land disposal for hazardous source material (i.e., soil, sludge, and solid waste, as opposed to ground water). Treatment technologies, in general, utilize chemical, biological, or physical processes that reduce the toxicity, mobility, or volume of wastes. Exhibit 4 shows mechanisms used in many of the technologies discussed in this document.

Although official definitions do not exist to distinguish among different stages of development status for alternative treatment technologies, the following functional definitions are generally accepted:

- **Available (or Existing) Technology.** A technology, such as rotary kiln incineration and conventional solidification/stabilization, that is fully proven in routine commercial use and for which sufficient performance and cost information are available.
- **Innovative Technology.** A treatment technology for which cost or performance information is incomplete, thus hindering routine use at hazardous waste sites. An innovative technology may require additional full-scale field testing before it is considered proven and ready for commercialization and routine use.
- **Emerging Technology.** Those technologies that require additional laboratory or pilot-scale testing to document the technical viability of the process.

Although this document is entitled "Innovative Treatment Technologies," the technologies discussed may fall into any of these development stages. However, the focus of this document is technologies which have at least been chosen for remediation. Examples of treatment technologies that fall into these groups are included in Exhibit 5. Exhibit 6 shows examples of the types of terms used in RODs grouped according to the technology being applied.

Treatment Technologies for Contaminated Soils

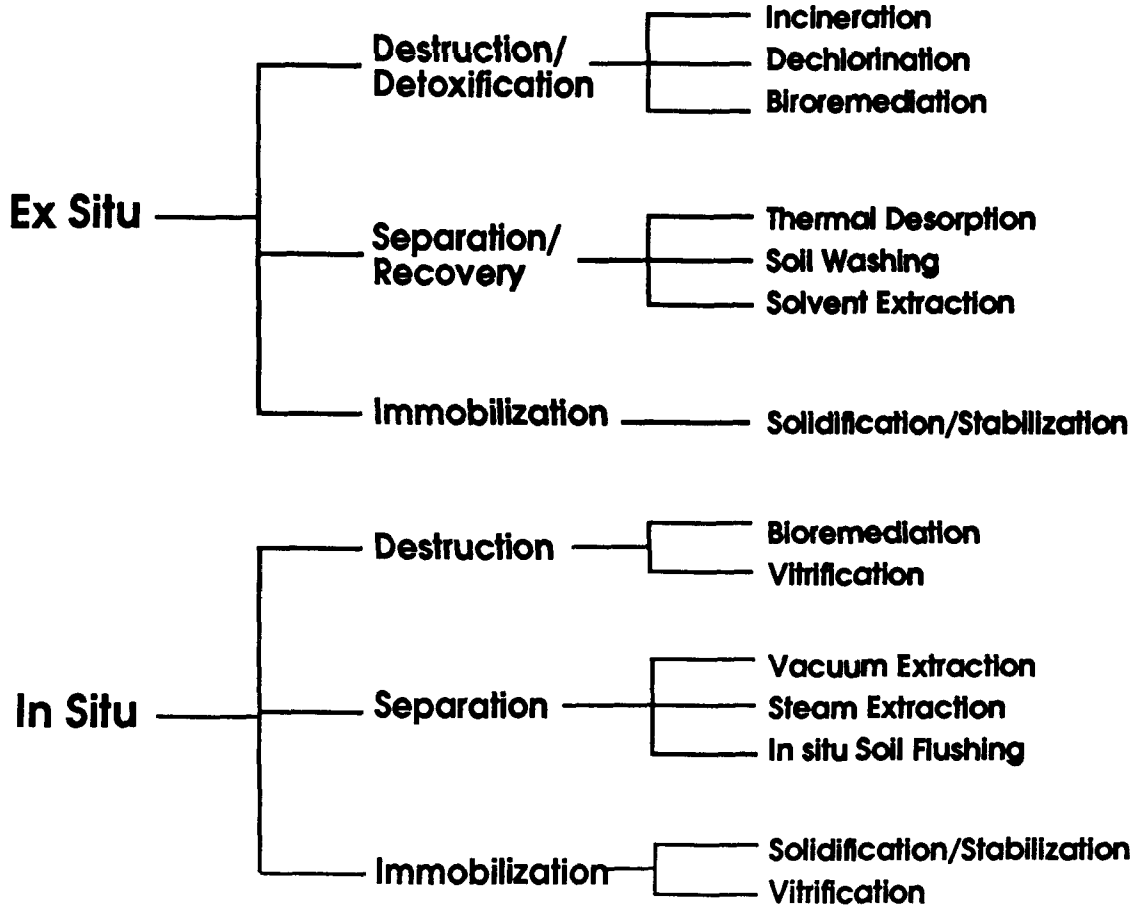


EXHIBIT 5 - STATUS OF SELECTED TECHNOLOGIES - SUPERFUND SOILS

Status of Selected Technologies

Superfund Soils

Emerging → Innovative → Established/ Available

Bench-scale Testing	Field Demonstration	Chosen for remediation	Limited full-scale use	Common full-scale use
In situ electro-kinetics	Bioventing	Soil washing	Thermal desorption	Incineration
	Radio-frequency heating	Solvent extraction	Land treatment bioremediation	Solidification/ stabilization
	Ex situ furnace vitrification	In situ bioremediation	Vacuum extraction	
		Slurry-phase bioremediation		
		In situ vitrification		
		In situ soil flushing		
		Dechlorination		

This chart shows the approximate status of soil treatment technologies in terms of their application at Superfund sites.

1.6 EXHIBIT 6 - TREATMENT TECHNOLOGY GROUPINGS

There are several terms that are used in practice to refer to the same technology for source control. The following is a list of terms that have been used primarily in RODs to describe source control technologies. The list is an attempt to classify these technologies and provide cursory information on their status. (A) indicates "Available Technologies." (I) indicates "Innovative Technologies."

1 On-/Off-site Incineration (A)

- Rotary Kiln
- Cement Kiln

2 Innovative Thermal Destruction (I)

- In Situ Vitrification
- Infrared Incineration

3 Immobilization (A)

- Solidification
- Stabilization
- Solidification & Stabilization
- Fixation

4 Vacuum Extraction (I)

- Soil Venting
- Vacuum Extraction
- Vapor Extraction
- Vacuum/Vapor Extraction
- In situ Volatilization

5 Bioremediation (I)

- In Situ Bioremediation
- In Situ Lagoon Bioremediation
- Slurry-Phase Bioremediation (Tank Bioremediation)
- Solid Phase Bioremediation - Land Farming
- Solid Phase Bioremediation - Land Application
- Solid Phase Bioremediation - Land Treatment
- On-site Bioremediation - Type Not Specified
- Bioremediation (Not Otherwise Specified)

6 In Situ Soil Flushing (I)

7 Soil Washing (I)

8 Chemical Extraction (I)

- Critical Fluid Extraction
- Solvent Extraction
- Hydrometallurgical Treatment
- Chemical Extraction

9 Chemical Destruction (I)

- Chemical Dechlorination
- KPEG Dechlorination

10 Thermal Desorption (I)

- Enhanced Volatilization
- Low Temperature Thermal Treatment
- Thermal Aeration
- Thermally Enhanced Volatilization
- Low Temperature Thermal Stripping
- Low Temperature Vaporization
- Low Temperature Thermal Extraction
- Low Temperature Thermal Aeration
- Low Temperature Incineration
- Thermal Distillation
- In Situ Steam Stripping
- In Situ Hot Air Stripping

11 Other/Not Specified Treatment (I)

- Soil Aeration
- Chemical Neutralization

The information in this manual was gathered from several sources and is intended to give its readers a broad overview of select technologies that may be applied at hazardous waste sites. The manual is designed for frequent updating to provide information which is as current as possible. The materials contained herein should be supplemented by further information-gathering and treatability studies during the remedy selection process when these technologies are being considered at a site.

OSCs/RPMs need up-to-date information on innovative treatment technologies because of the rapid developments in this field. To ensure the most complete and up-to-date information is used in the decision-making process, technology experts should be consulted during the process. The document entitled, "Technical Support Services for Superfund Site Remediation, EPA/540-8-90/011," included as an appendix to this guide (Exhibit 11.10) is a good starting point for additional information. Exhibit 11.12, "Selecting Innovative Treatment Technologies: A Practitioner's Guide," discusses other sources of information on innovative technologies. The paper highlights the following EPA reference guides to technical experts:

Ground Water Research: Technical Assistance Directory EPA/600/9-89/048

Environmental Protection Agency, Office of Research and Development: Technical Assistance Directory CERI-88-84

ORD Topical Directory EPA/600/9-86/006

Technical Support Services for Superfund Site Remediation, EPA/540/8-90/011, October 1990. (Exhibit 11.10 of this guide)

A significant source of information in this document manual was the Innovative Treatment Technologies: Semi-Annual Status Report which was first released by the Technology Innovative Office (TIO) in January, 1991 and updated in September. This report provides information on National Priorities List (NPL) sites and emergency response sites where EPA has selected or used innovative treatment technologies. The information contained in the report serves several purposes: (1) to track the progress of innovative technology use; (2) to provide market information to technology vendors; and (3) to facilitate communication among innovative technology users. This report will be updated and distributed biannually. In several sections of this manual you will see tables excerpted from the September 1991 status report. In Exhibit 7 and Section 11.13 there are several summary statistics and charts that have been derived from the contents of the status report to give an overall view of the progress and status of innovative treatment technologies. To get on the mailing list for future updates of this document call Ms. Dana Mun of PRC, at (703) 556-2783. To receive a copy of the most recent report, you may call EPA/ORD Publication at (513) 569-7562 and request document number EPA/540/2-91/002.

For further information on this guide or other TIO initiatives, call Mr. John Quander at FTS/398-8845 or (703) 308-8845.

Remedial Actions: Project Status of Innovative Treatment Technologies as of August 1991

Technology	Predesign/ In Design	Design Complete/ Being Installed/ Operational	Project Completed	Total
Vacuum Extraction	36	12	1	49
Ex Situ Bioremediation	15	4	1	20
Thermal Desorption	14	0	3	17
Soil Washing	16	0	0	16
In Situ Bioremediation †	8	2	1	11
In Situ Flushing	9	2	0	11
In Situ Vitrification	5	0	0	5
Solvent Extraction	4	1	0	5
Dechlorination	3	1	1	5
Chemical Treatment	0	0	1	1
TOTAL	***110 (78%)***	***22 (16%)***	***8 (6%)***	***140***

* Data derived from 1982 – 1990 Records of Decision (RODs) and anticipated design and construction activities.

† Includes in situ groundwater treatment.

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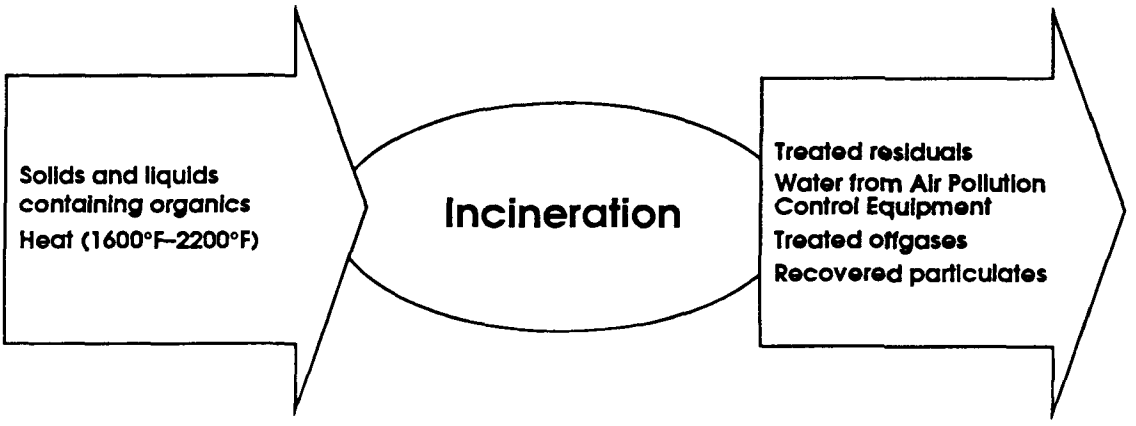
2.0 INCINERATION

2.1 TECHNOLOGY DESCRIPTION

Incineration uses high temperatures ranging from 1600 to 2200°F (871 to 1204°C) to volatize and combust (e.g., in the presence of oxygen) organic constituents in hazardous wastes. Three common incinerator designs are rotary kilns, infrared furnaces, and circulating fluidized bed incinerators. The destruction and removal efficiency (DRE) for properly operated incinerators often exceeds the 99.99 percent requirement for hazardous waste. All of these designs can be operated to meet the 99.9999 percent requirement for PCBs and dioxins. Incinerators usually have primary and secondary combustion units to reach this efficiency.



- Rotary kiln
- Infrared
- Circulating fluidized bed
- Others

2.1.1 Rotary Kiln

Rotary kiln incinerators are slightly inclined, refractory-lined cylinders used for the controlled combustion of organic wastes under net oxidizing conditions (i.e., the final oxygen concentration is significantly greater than zero.)

Wastes and auxiliary fuel are injected into the high end of the kiln and passed though the combustion zone as the kiln slowly rotates. Rotation of the combustion chamber creates turbulence and improves the degree of burnout of the solids. Retention time can vary from minutes to an hour or more. Wastes are oxidized to gases and inert ash. Ash is removed at the lower end of the kiln and flue gases are passed through a secondary combustion zone and then through air pollution control units.

Residuals generated from the process include: (1) ash, (2) stack gases, and (3) brine solution for the ash quench and wet scrubber.

2.1.2 Infrared

Infrared thermal units use silicon carbide elements to generate thermal radiation beyond the red end of the visible spectrum. Materials to be treated pass through the treatment unit on a conveyer belt; off gases are passed to a secondary chamber for additional thermal treatment.

Residuals from an infrared system are the same as from a rotary kiln - ash, stack gases, and scrubber water.

2.1.3 Circulating Fluidized Bed

The fluidized bed incinerator consists of a refractory-lined vessel containing a bed of inert, granular, sand-like material. Combustion air is forced upward through the bed thereby suspending the material. Fluidized beds can be operated at lower temperatures than other incinerators because of the high mixing energies aiding combustion. Fluidized beds also make use of limestone for the capture of acid gases, thus eliminating the need for wet scrubbers and one of the residual streams from the process.

2.2 TECHNOLOGY STATUS

- A recent survey of the thermal incineration industry shows 14 active mobile cleanup vendors (nine rotary kilns, four infrared furnaces, and one circulating fluidized bed).
- Through FY 90, 55 RODs approved off-site incineration and 59 approved on-site incineration.
- There is limited capacity for off-site incineration of soils.
- Rotary kiln, infrared, and circulating fluidized bed incinerators have been successfully demonstrated and used in full scale remediation.

2.3 APPLICATIONS

- Incineration is effective in treating soils, sediments, sludges, liquids, and gases.
- Incineration is used to treat all concentrations of organic constituents. It becomes more competitive when high concentrations are present and other treatments are not possible.

2.4 TECHNOLOGY STRENGTHS

- Incineration usually destroys organic contaminants in the residual soils with an efficiency of greater than 99.9 percent.
- The treatment concentrates non-volatile metal constituents in residues.
- It may accomplish some volume reduction of soils depending on the ash content.

2.5 TECHNOLOGY LIMITATIONS

- Incineration is relatively expensive compared to other technologies.
- Public resistance has been high.
- Volatile metals, including lead and arsenic, leave the combustion unit with the flue gases and may have to be removed to avoid excessive emissions. (See Exhibit 3). Metals can react with other elements in the feed stream such as chlorine or sulfur, forming more volatile and toxic compounds than the original species.
- Sodium and potassium in the wastes can attack the brick lining of the thermal unit (refractory attack) and form a sticky particulate which fouls heat transfer surfaces.

- Acid gases must be removed when wastes are combusted which contain halogenated, sulfonated, nitrated or phosphorus compounds.

2.6 POTENTIAL MATERIALS HANDLING REQUIREMENTS

- Excavation is required.
- Dewatering may be necessary to achieve acceptable soil moisture content. (The cost of incineration increases as the moisture content increases. In addition, infrared treatment units require more than 22 percent solids to ensure proper conveyance.)
- The material must be screened to remove oversized particles.
- Size reduction may be needed to achieve the feed size required by the equipment.
  - The rotary kiln has the least stringent requirement (can accept debris up to 12 inches in diameter.)
  - Fluidized bed units and infrared units require the waste material to be less than 1 to 2 inches in diameter.
- The waste material may require mixing to achieve uniform feed size and moisture content and to dilute troublesome components.
- If the wastes contain a high concentration of clays and fine particles, separation of clays and fines will minimize dust emissions and particulate loadings to the air-pollution control equipment (rotary kiln and fluidized bed).

2.7 WASTE CHARACTERISTICS AFFECTING PERFORMANCE

- See table on attached page.

	Rotary Kiln	Circulating Fluidized Bed	Infrared Processing System
Process Technology	Well-developed and proven, extensive operating experience	Developed, more limited operating experience	Developed, more limited operating experience
Destruction Capabilities	Demonstrated destruction of toxic organics including PCBs and dioxins, secondary combustion chamber required	Demonstrated destruction of toxic organics including PCBs, secondary combustion chamber not required	Demonstrated destruction of toxic organics including PCBs (full-scale), and dioxins (pilot-scale), secondary combustion chamber required
Gas Volume	Large gas volume due to high excess air requirements	Moderate gas volume	Low gas volume
Mobilization	Longest set-up time, larger set-up area required	Smallest set-up area required, shortest set-up time	Second longest set-up time
Solid Feed Size	Non-uniform feed size acceptable, maximum size typically 12 inches	Uniform feed size of less than 1 inch required for all solids	Uniform feed size of less than 2 inches required for all solids
Acid Gas Control	External scrubbing system required	Acid gas absorbed in the circulating bed. No external control necessary	External scrubbing system required
Particulate Loading	High particulate loading due to kiln rotation, high excess air requirements	High particulate loading due to the turbulent nature of the bed	Low particulate loading due to the quiescent nature of the bed
Combustion Chamber Insulation Material	Refractory brick susceptible to attack by alkali metals and acid gases. Rebricking may be necessary in order to transport	Refractory brick susceptible to attack by alkali metals and acid gas	Ceramic fiber insulation immune to thermal shock and lighter than refractory brick
Process Water Required for Scrubbing Closed-Looped	Process water (and wastewater water scrubber, all cooling system	No process water required, no disposal required for scrubbing	Process water (and wastewater disposal system)
Energy Source	Fuel oil, natural gas, propane and/or waste liquids	Fuel oil, natural gas, propane, waste liquids	Electric power for primary, propane and/or waste liquids for secondary
System Capacity	Available mobile systems up to 20 tons per hour	Available mobile systems up to 3 tons per hour	Available mobile systems up to 3 tons per hour

SECTION 2.8 EXHIBIT 1 - COMPARATIVE ANALYSIS OF INCINERATION TECHNOLOGIES

Source: High Temperature Thermal Treatment for CERCLA Waste: Evaluation and Selection of Onsite and Offsite Systems, EPA/540/4-89/006 (1988)

2.9 EXHIBIT 2 - WASTE CHARACTERISTIC TABLES

Waste Type: Soils and Sludges
Technology: High-Temperature Thermal Treatment - General*

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
High moisture content	Moisture content affects handling and feeding and has major impact on process energy requirement.	Analysis for percent moisture
Elevated levels of halogenated organic compounds	Halogens form HCl, HBr, or HF when thermally treated; acid gases may attack refractory material and/or impact air emissions.	Quantitative analysis for organic Cl, Br, and F
Presence of PCBs, dioxins	PCBs and dioxins are required to be incinerated at higher temperatures and long residence times. Thermal systems may require special permits for incineration of these wastes.	Analysis for priority pollutant.
Presence of metals	Metals (either pure or as oxides, hydroxides, or salts) that volatilize below 2,000°F (1,093°C) (e.g., As, Hg, Pb, Sn,) may vaporize during incineration. These emissions are difficult to remove using conventional air pollution control equipment. Furthermore, elements cannot be broken down to nonhazardous substances by any treatment method. Therefore, thermal treatment is not useful for soils with heavy metals as the primary contaminant. Additionally, an element such as trivalent chromium (Cr^{+3}) can be oxidized to a more toxic valence state, hexavalent chromium (Cr^{+6}), in combustion systems with oxidizing atmospheres.	Analysis for heavy metals
Elevated levels of organic phosphorous compounds	During combustion processes, organic phosphorous compounds may form phosphoric acid anhydride (P_2O_5), which contributes to refractory attack and slagging problems.	Analysis for phosphorus

Applicable to fluidized bed, infrared, rotary kiln, wet air oxidation, and pyrolytic as well as vitrification processes.

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

2.9 EXHIBIT 2 - WASTE CHARACTERISTIC TABLES (continued)

Waste Type: Soils and Sludges
Technology: Rotary Kiln Incineration

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Oversized debris such as large rocks, tree roots, and steel drums	Difficult to handle and feed; may cause refractory loss through abrasion. Size reduction equipment such as shredders must be provided to reduce solid particle size.	Size, form, quantity of oversized debris. Size reduction engineering data
Volatile metals (Hg, Pb, Cd, Zn, Ag, Sn)	May result in high metals concentration in flue gas, thus requiring further treatment.	Soil and stack gas analysis for subject metals
Alkali metal salts, particularly sodium and potassium sulfate ($NaSO_4$, KSO_4)	Cause refractory attack and slagging at high temperatures. Slagging can impede solids removal from the kiln.	Percent Na, K
Fine particle size of soil feeds such as clay, silts	Results in high particulate loading in flue gases due to the turbulence in the rotary kiln.	Soil particle size distribution, USGS*** soil classification
Spherical or cylindrical wastes	Such wastes may roll through the kiln before complete combustion can occur.	Physical inspection of the waste
Ash fusion temperature of waste	Operation of the kiln at or near the waste ash fusion temperature can cause melting and agglomeration of inorganic salts.	Ash fusion temperature
Heating value of waste	Auxiliary fuel is normally required to incinerate wastes with a heating value of less than 8,000 Btu.	Btu content

*** U.S. Geological Survey.

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

2.9 EXHIBIT 2 - WASTE CHARACTERISTIC TABLES (continued)

Waste Type: Soils and Sludges
Technology: Fluidized Bed Incineration

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Feed particle size	Large particle size affects feeding and removal of solids from the bed. Solids greater than 1 inch (2.5 cm) must be reduced in size by shredding, crushing, or grinding. (Note: Waste-Tech fluid bed systems can handle up to 3-in feed.) Fine particles (clays, silts) result in high particulate loading in flue gases.	Size, form, quantity of solid material; size reduction engineering data; soil particle size distribution; USGS soil classification
Low-melting point (less than 1600°F) constituents, particularly alkali metal salts and halogens (e.g., Na, Cl compounds)	Defluidization of the bed may occur at high temperatures when particles begin to melt and become sticky. Melting point reduction (eutectics) may also occur. Alkali metal salts greater than 5% (dry weight) and halogen greater than 8% (dry weight) contribute to such refractory attack, defluidization, and slagging problems.	Ash fusion temperature
Ash content	Ash contents greater than 64% can foul the bed. (Note: Waste-Tech's continuous bed letdown, screening, and reinjection minimize this type of problem.)	Ash content
Waste density	As waste density increases significantly, particle size must be decreased for intimate mixing and heat transfer to occur.	Waste-bed density comparison
Presence of chlorinated or sulfonated wastes	These wastes require the addition of sorbents such as lime or sodium carbonate into the bed to absorb acidic gases or the addition of a flue gas scrubbing system as part of the treatment train.	Analysis for priority pollutants

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

2.9 EXHIBIT 2 - WASTE CHARACTERISTIC TABLES (continued)

Waste Type: Soils and Sludges
Technology: Infrared Thermal Treatment

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Nonhomogeneous feed size	Nonuniform feed size requires pretreatment before feeding and conveyance through the system. The largest solid particle size processible is 1 to 2 inches. Debris such as rocks, roots, and containers must be crushed or shredded to allow for feeding.	Size, form, quantity of solid material; size reduction engineering data
Moisture content	Since waste material is conveyed through the system on a metal conveyor belt, soils and sludges must be firm enough (usually > 22% solids) to allow for proper conveyance. Soils and sludges with excess water content (e.g., lagoon sediments) require dewatering prior to feeding.	Moisture analysis

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

2.10 EXHIBIT 3 - BOILING POINTS OF SELECTED COMPOUNDS

Chemical Name	Boiling Point °F	(°C)
$BeCl_2$	7,052	(3,900)
Uranium and Compounds	6,904[a]	(3,818)
Iron	4,982[a]	(2,750)
$FeCl_2$	1,238	(670)
$FeCl_3$	599	(315)
Nickel	4,949[a]	(2,732)
Chromium	4,842[a]	(2,672)
CrO_2Cl_2	243[a]	(117)
Chromium, hexavalent	4,500	(2,482)
Copper	4,653[a]	(2,567)
CuCl	2,491	(1,366)
$CuCl_2$	1,819[a]	(993)
Manganese and Compounds	3,564[a]	(1,962)
Lead (Pb)	3,171[a]	(1,744)
$PbCl_2$	1,742	(950)
Barium	2,084	(1,140)
BaO	3,632	(2,000)
Zinc	1,665[a]	(907)
ZnO_2	3,272	(1,800)
$ZnCl_2$	1,350	(732)
Cadmium	1,409[a]	(765)
CdO	1,652-1,832	(900-1,000)
$CdCl_2$	1,760	(960)
$SnCl_2$	1,153	(623)
Arsenic	1,135[a]	(613)
As_2O_3	379	(193)
2,3,7,8-dioxin	932-1,500[c]	(500-800)
Mercury	675	(357)
HgCl	575	(302)
Phenanthrene	644	(340)
SeO_2	603	(317)
Pentachlorophenol	588	(309)
Fluorene	559	(293)
Lindane	550	(288)
Polychlorinated biphenyls	512+	(267+)
Pyrene	500	(260)
DDT	500	(260)
Methanol	360	(182)
Styrene	293	(145)
Xylene	280	(138)
Ethylbenzene	277	(136)

Note: The boiling points of metals and metal compounds are of concern in the design of hazardous waste incinerators. Temperatures in the primary chamber of these incinerators may exceed 1800 ° F, and the secondary combustion chamber often exceeds 2200 ° F. At these temperatures many of the metals and metallic compounds listed above will exist in the gas phase. Capture of the gaseous forms of these compounds requires expensive modifications to the air pollution control systems.

[a] Boiling point is for the pure chemical itself and may not reflect that for the various compounds.

[b] Sublimates.

[c] Decomposes.

2.10 EXHIBIT 3 - BOILING POINTS OF SELECTED COMPOUNDS (Continued)

Chemical Name	Boiling Point °F	(°C)
Chlorobenzene	270	(132)
Tetrachloroethane	264-295	(129-146)
1,1,2,2-tetrachloroethane	295	(146)
Tetrachloroethene	250	(121)
1,1,2-trichloroethane	235	(113)
Toluene	232	(111)
Trichloroethylene (TCE)	189	(87)
1,2-dichloroethane	183	(84)
Methyl ethyl ketone	176	(80)
Benzene	176	(80)
Carbon tetrachloride	171	(77)
1,1,1-trichloroethane	165	(74)
Chloroform	142	(61)
Cis-1,2-dichloroethylene	140	(60)
1,1-dichloroethane	135	(57)
Acetone	133	(56)
1,2-trans-dichloroethylene	118	(48)
Methylene chloride	106	(41)
1,1-dichloroethene	90	(32)
Cyanides (for HCN)	80	(27)
Naphthalene	70	(21)
Vinyl chloride	7	(-13.9)

United States Environmental Protection Agency

Office of Waste Programs Enforcement Washington, D.C. 20460

Winter 1987 S/AT/87-2

FACT SHEET: Incineration Of Hazardous Waste

EPA

Introduction

Hazardous waste is produced as a result of current manufacturing processes that supply products we use daily, from food, clothing, and shelter to recreation and health care products. Hazardous waste is often a result of mixing chemical compounds that are produced and shipped by a number of separate industries. A national survey conducted by the Environmental Protection Agency (EPA) in 1986 estimated that 247 million metric tons of hazardous waste are managed in regulated facilities nationwide each year -- roughly one ton per every man, woman and child in the United States. Dealing with hazardous waste safely, then, is a major responsibility that rests with each of us. Properly managing such waste requires close coordination among Federal agencies, State and local government, private industry, and the public.

Until the late 1970s, land disposal was the cheapest and, thus, preferred means of disposing of hazardous waste. Experience at some landfills since that time, however, has demonstrated the potential for serious health and environmental impacts from improper land disposal. Recognizing this threat to human health and the environment, Congress revised the Resource Conservation and Recovery Act (RCRA)-- the law that regulates the handling of hazardous waste. Recent revisions to RCRA discourage future land disposal of hazardous waste by placing stringent limits on the types of wastes that can be disposed of in this manner.

As a consequence, more and more hazardous waste producers, as well as operators and owners of treatment and disposal facilities, are using methods other than land disposal to handle wastes. EPA also is seeking, where appropriate, to use alternatives to land disposal for dealing with hazardous substances from sites regulated under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund). CERCLA was reauthorized on October 17, 1986, with the enactment of the Superfund Amendments and Reauthorization Act (SARA). EPA is hopeful that many treatment technologies will be demonstrated and available for full-scale use in the coming years. The Superfund Innovative Technology Evaluation (SITE) program was established to support such demonstrations.

Incineration is one of the available alternative technologies to treat many types of hazardous waste. Incineration can destroy organic waste such as dioxins and polychlorinated biphenyls (PCB). Furthermore, this method can handle waste in many forms including soils, drums of sludges and solids, and liquids. Some types of incineration even allow for recovery of energy or materials.

Incineration has been used to destroy hazardous waste in the U.S. and Europe for several decades. EPA has studied and tested commercial incinerators and has conducted incineration research for several years. Based upon EPA's current knowledge, well-operated incinerators safely destroy hazardous wastes. EPA is continuing to study incineration in an effort to gather additional data on how best to incinerate hazardous waste and minimize the potential for harmful emissions.

What Is Hazardous Waste Incineration And How Does It Work?

During hazardous waste incineration, the individual molecules of many organic hazardous materials are efficiently broken down into their basic atomic elements and detoxified using high temperature heat and flame (typically 1800° F to 2500° F). These basic elements (hydrogen, carbon, chlorine, nitrogen, etc.) are oxidized into safer and more stable

materials such as water, carbon dioxide, and nitrogen oxides. Some inert ash or residues, organic-free particulates, and small concentrations of organic materials remain. How these remaining materials are captured is discussed later in this fact sheet. Properly done, high-temperature incineration is a safe, efficient, odorless, and smokeless process that renders many of the most toxic organic wastes permanently harmless.

Two major types of hazardous waste incinerators are in use today: the liquid injection system, which is limited to burning liquid wastes, and the rotary kiln incinerator, which is used to burn solids as well as liquids. Other types of hazardous waste incinerators being used include the "fluidized bed incinerator" and the "infrared incinerator." The type of hazardous waste incineration chosen depends upon the kind of hazardous waste to be incinerated, its physical state (e.g., liquid or solid), and the way it is handled and stored prior to incineration. Many incinerators in operation today combine these types for more effective handling and destruction.

What Kinds of Hazardous Waste Can Be Incinerated?

All hazardous wastes can be incinerated. Incineration, however, destroys only organic material (PCBs, dioxins, etc.), not inorganic materials such as hydrochloric acid, salts, and metals. Wastes that contain a mixture of materials including organic, inorganic and metal waste may be treated by incineration to detoxify the organic waste.

Are Highly Toxic Wastes Destroyed by Incineration?

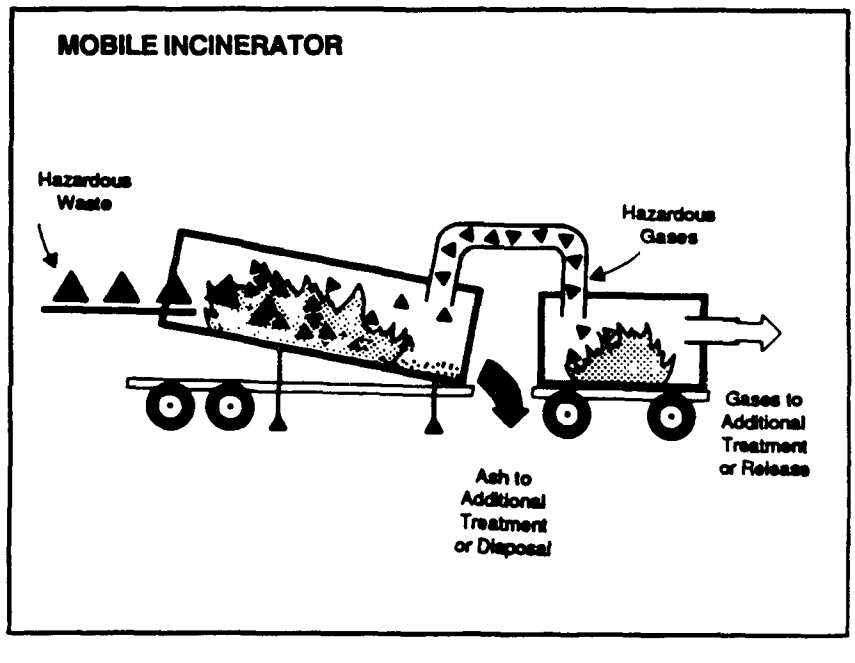
A common misconception is that the more toxic a chemical, the more difficult it is to burn. While some chemicals are more easily broken down through incineration than others, ease of thermal decomposition is not related to toxicity. EPA has determined through an extensive incineration research and evaluation program that destruction of organic wastes occurs irrespective of toxicity. This feature is very important because it means that chemicals ranging from pesticides to PCBs, benzene to dioxin, all break down under heat, provided that appropriate conditions are met.

Where Are Hazardous Waste Incinerators Located?

Hazardous waste incinerators that are built and operated where the hazardous wastes are generated are called <u>on-site</u> incinerators. They are typically constructed near a chemical plant or manufacturing site. On-site incinerators also can be built at Superfund sites if the amount of waste that needs to be incinerated is large. In 1985 there were 235 on-site facilities that handled 90 percent of the hazardous waste incinerated each year in the United States.

An <u>off-site</u> incinerator is also referred to as a "commercial facility" because hazardous waste shipped from a variety of generators is incinerated at a single facility. Currently, 16 commercial hazardous waste incineration facilities are in use throughout the U.S., accounting for roughly 10 percent of the hazardous waste incinerated. Most commercial facilities are currently operating at or near full capacity. Because of the large amount of wastes at Superfund sites that can be incinerated, commercial incinerator capacity will likely fall short of needed capacity in the near future.

A useful innovation for destruction of hazardous waste is the <u>mobile (or transportable)</u> incinerator. These systems are hauled to a site on flat bed trucks, then assembled and tested. Mobile incinerators typically have a smaller capacity than stationary, on-site units. Because mobile incinerators are designed to be moved, they are usually smaller than most stationary facilities. Mobile incinerators are particularly appropriate for Superfund sites, especially when the waste at those sites can be cleaned up in a limited period of time.



At What Rate Can An Incinerator Handle The Waste?

The rate an incinerator can handle waste generally depends on the volume and type of hazardous waste to be destroyed and the specific conditions at a site. For example, hazardous wastes are typically fed into the mobile rotary kiln incinerator at a rate of 10,000 pounds per hour for contaminated solids and 7,000 pounds per hour for liquids. In a mobile liquid injection system, wastes typically can be fed at 1,500 gallons (over 12,000 pounds) per hour. These quantities can be compared to those of non-hazardous waste burned by many municipal incinerators, some of which handle 1,000 tons (2 million pounds) of waste per day.

Are All Hazardous Wastes Completely Destroyed During Incineration?

No incinerator can destroy 100 percent of the hazardous waste. Minute amounts of hazardous compounds are released into the air through the incinerator stack (chimney) or become mixed with the ash. However, EPA requires that each incinerator achieve a satisfactory performance level. A standard of at least 99.99 percent has been set for destruction and removal of hazardous compounds introduced into incinerators. For PCBs and dioxins, incinerators must demonstrate a destruction and removal efficiency (DRE) of 99.9999 percent. A 99.99 percent DRE means that of every 10,000 pounds introduced into the incinerator, at the most, only one pound of residuals remain. For PCBs and dioxin compounds, the higher DRE of 99.9999 percent means that one pound of residuals for every million pounds introduced into the incinerator may remain. EPA has tested incinerators and found that they can meet or exceed these standards if operated properly. In addition, EPA believes that, based on current knowledge, these standards protect human health and the environment.

How Does EPA Know That Performance Standards Are Met?

To ensure that an incinerator can operate at the established performance level, trial burns are conducted. Trial burns use samples of different hazardous wastes, such as paints, sludges, or chemical solvents, that are expected to be burned in a particular incinerator. The trial burn is designed to test the unit under the most difficult conditions the incinerator will experience during normal operations. For each batch of mixed waste, EPA selects up to six of the most concentrated and most difficult-to-incinerate compounds. By demonstrating that these compounds are destroyed and removed to a 99.99 percent performance level, trial burns demonstrate the maximum performance of the incinerator. In addition, any time an incinerator is to burn a new waste containing a more difficult-to-incinerate compound than the test compound, a sample of this waste is testburned to guarantee that it will be destroyed to 99.99 percent efficiency. If it cannot be destroyed to that efficiency, the waste may not be burned at that incinerator.

The results of the trial burn are used to set the conditions under which the incinerator must operate to ensure that it meets the performance standard. EPA specifies these conditions in the operating permit for each incinerator . The permit outlines the maximum allowable carbon monoxide level in the stack exhaust gas, the maximum waste feed rate, the minimum combustion temperature, the appropriate indicator for combustion gas velocity, allowable variations in incinerator system design or operating procedures, and other parameters necessary to ensure proper operation. Hazardous waste cannot be fed into the incinerator unless the incinerator is operating within these specified conditions. When conditions deviate from these established permit limits, the incinerator triggers a waste feed cut-off system thereby ensuring no emission of hazardous waste from the incinerator.

What Happens to the Residuals Produced by Incineration?

Under EPA's incinerator regulations, ash that is removed from the incinerator (both at the bottom of the unit and from the stack) is always assumed to be hazardous and must be disposed of at a RCRA-permitted facility. EPA may be petitioned to "delist" the residue to formally determine that it is not a hazardous waste. If the residue is determined (through chemical analysis) to be non-hazardous, it may be disposed of in a municipal landfill. In addition, scrubber water must meet the Clean Water Act standards to protect public health and the environment before it can be discharged to a river, stream, or lake.

How Much Does Incineration Cost?

The cost of off-site, commercial incineration varies widely. Many factors influence costs, including concentration of the hazardous waste, its physical state (e.g., liquid or solid), its potential for burning, the manner in which it is fed into the incinerator, and pretreatment requirements. The size and characteristics of the incinerator also affect costs. The use of mobile or on-site incinerators can, in some cases, reduce the costs of treating the more

difficult wastes. More experience with using mobile and on-site facilities for Superfund cleanup is needed, however, to determine actual costs.

Who Regulates Hazardous Waste Incineration Facilities?

All off-site and on-site hazardous waste incinerators are regulated by EPA or the appropriate State government acting under the authorization of EPA. Incineration is one of the final steps in the "cradle to grave" regulatory management system created by Congress under the RCRA legislation. "Cradle to grave" means that from the point at which a hazardous waste is generated to its ultimate destruction or disposal, it must be managed and monitored to ensure protection of human health and the environment.

Under RCRA, all incineration facilities except those at Superfund sites must obtain a permit to operate. Although a permit is not required for on-site incineration at a Superfund site, EPA complies with the substantive requirements of RCRA, including the technical requirements pertaining to permitting. If hazardous waste from a Superfund site is sent to an off-site incinerator, the incinerator must comply with all RCRA requirements, including permitting.

To receive a permit, owners and operators of incinerators are required to submit information on the design, operation, and future closure of the facility. They also must submit information on the financial capability to cover closure of the facility and liability for bodily injury or property damage to third parties. The information submitted by the permit applicant must specify what analyses will be made of all hazardous wastes prior to incineration to ensure that the wastes are suited to the technology. Security measures, such as installation of a fence around the facility and adequate surveillance, also are required. Further, owners and operators must develop and follow a written inspection schedule to assess the overall safety of the facility, and they must use trained facility personnel. Owners and operators also must prepare an action plan for emergency situations and ensure that emergency prevention measures are taken. Finally, up-to-date recordkeeping and reporting on the operation of the facility are required.

Who Monitors the Incineration Process During a Superfund Response?

During a Superfund response, EPA or the State will lead the technical activity or monitor the activities of the State or private party conducting the cleanup. Private firms, however, will actually conduct the cleanup activity at the Superfund site. If mobile or on-site incineration is the chosen cleanup option, highly trained incineration engineers from commercial incineration firms will operate the incinerator system. EPA or the State, as part of their monitoring of contractor performance, will monitor trial burns of the incineration process, and will inspect incinerators at least twice a year (as required by RCRA) to ensure that safety and health practices are being followed and wastes are being destroyed effectively.

How Can The Public Participate in the Process?

EPA provides several opportunities for public participation when initiating activities at a Superfund site. In a report called the feasibility study, EPA or the State must describe the options that it is considering for dealing with hazardous wastes at the site. One of these options may be incineration either at the site (mobile or on-site) or at a commercial facility located offsite. The public will have a minimum of three weeks to comment on treatment and disposal options documented by the feasibility study. EPA must consider and address these public comments before it decides which option to use. In addition, EPA or the State generally will hold public meetings and issue status reports to keep the community advised of site activities, site conditions, and opportunities to participate in meetings. For additional information, a Superfund Regional contact is provided below.

SUPERFUND CONTACT:

1990 Thermal Remediation Industry Contractor Survey

James J. Cudahy and William L. Troxler
Focus Environmental, Inc.
Knoxville, Tennessee

The treatment of soil contaminated with organics and inorganics is becoming a major industry in the United States and Europe. The soil cleanup bill for the United States could run as high as $200 to $300 billion over the next 30 to 40 years. European soil cleanup costs could run as high as $130 billion.[1]

The types of sites in the United States that will require soil treatment can be broken down into the following categories:

- *CERCLA (Superfund) Actions*
- *RCRA Corrective Actions*
- *RCRA Closures*
- *Underground Storage Tanks*
- *Real Estate Transfers*
- *Spill Clean-ups.*

(Continued on next page).

Thermal Remediation Equipment

The terms *mobile* and *transportable* are often used interchangeably, however, this is often misleading. For purposes of this paper, a *mobile* thermal treatment system is defined as a truck, rail, barge, or skid-mounted system which can be field erected in two weeks or less and requires minimal foundations. A *transportable* thermal treatment system is defined as a truck-, rail-, barge- or skid-mounted system which requires more than two weeks for field erection and requires the construction of subetantial foundations.

The following types of mobile and transportable thermal remediation

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The cleanup of sites in each of these categories, with the exception of the Real Estate Transfer category, is being driven by different sets of Federal regulations. Real Estate Transfer type regulations were first instituted in New Jersey and have now been promulgated in a number of other states.

The eventual cleanup cost for the Superfund sites will be close to $200 billion. Estimated costs for the industrial sector Superfund are $25 to $50 billion and the estimated cost for the Department of Energy sites is over $150 billion.[2] An early RCRA Corrective Action cleanup estimate is $25 billion.[3] This estimate may well be low, however, since the permitting, cleanup and delisting criteria are still not clearly defined. The EPA's RCRA Corrective Action cost estimate is $7.4 billion. However, the Office of Management and Budget feels that this estimate is low.[4]

The potential magnitude of the cleanup costs has resulted in the development and implementation of many technologies for the decontamination of soils. Of the available remedial technologies, thermal treatment has perhaps had the most field testing. The purpose of this paper is to focus on the full scale site remediations which have been or are being conducted using thermal processing equipment. Projects which have been completed, are on-going, or have been contracted for, through January of 1990 are described.

equipment are currently available for soil decontamination:

- Rotary kiln
- Circulating bed combustor
- Infra-red conveyor furnace
- Asphalt kiln
- Low temperature direct fired desorber
- Low temperature indirect fired desorber
- High temperature indirect fired desorber.

The types of systems listed above have all been used or are under contract to perform full-scale site cleanups. Descriptions of these systems can be found in References 5 through 8.

Thermal Remediation Projects

The projects described in this paper do not include pilot scale work. A description of some of the early pilot scale thermal treatment work can be found in References 5 and 8. The thermal remediation projects detailed in this paper are all full-scale commercial cleanups in the United States which are either completed, on-going, or have been contracted. The project information was obtained by contacting each of the thermal remediation service contractors and asking for the following information:

- Site name/location/size (tons)
- Source of contamination
- Project status (finished, on-going, or contracted)
- Combustion equipment type and capacity (MM Btu/hr)
- Air pollution control equipment type
- Number of units used by contractor during the project
- Treated soil indicator compound
- Concentration of indicator compound in treated soil
- Requirement for a trial burn
- Particulate emissions during trial burn
- RCRA or TSCA permitting requirements
- Biggest problem on project.

Table I. Thermal remediation industry project summary.

Description	Project status			
	Finished	On-going	Contracted	Total
No. of projects	31	8	15	54
Waste quantity (tons)	340,000	370,000	565,000	1,275,000
Average site size (tons)[a]	11,000	46,300	37,700	23,600
No. of contractors				20
No. of thermal units				40

[a] Average includes only projects for which site size information is available.

Table II. Site data.

Vendor	Site name	Site location	ST	Source of contamination	Project status	Site size (tons)
AET	Valdez	Valdez	AK	Crude oil spill	Finished	
Canonie	Ottati & Goss	Kingston	NH	Solvent treatment	Finished	8,000
Canonie	Canon Bridgewater	Bridgewater	MA	Solvent recycling	Contracted	6,500
Canonie	South Kearny	South Kearny	NJ	Solvent recycling	Finished	18,000
Canonie	McKin	Gray	ME	Waste treatment and disposal	Finished	18,000
Chemical Waste Mgt.	Confidential	Northeast		PCB spills	Contracted	35,000
Ensco	Union Carbide	Seadrift	TX	Chemical manufacturing	Contracted	
Ensco	Lenz Oil	Lemont	IL	Waste oil	Finished	26,000
Ensco	Sydney Mines	Brandon	FL	Waste oil lagoon	Finished	10,000
Ensco	NCBC	Gulfport	MS	Herbicide storage	Finished	22,000
Ensco	Bridgeport Rental	Bridgeport	NJ	Used oil recycling	Ongoing	100,000
Ensco	Smithville	Canada		PCB transformer leaks	Contracted	7,000
GDC Engineering	Rubicon	Geismar	LA	Chemical manufacturing	Ongoing	52,000
Harmon	Bog Creek	Howell Twp.	NJ	Paint/solvent disposal	Ongoing	22,500
Harmon	Confidential		AL	Gasoline tank leak	Finished	600
Harmon	Prentiss Creosote	Prentiss	MS	Wood treatment	Finished	9,200
IT Corporation	Motco	Lamarque	TX	Styrene tar disposal pits	Ongoing	80,000

(Continued on next page).

Table II. Site data (continued).

Vendor	Site name	Site location	ST	Source of contamination	Project status	Site size (tons)
IT Corporation	Cornhusker AAP	Grand Island	NE	Munitions plant redwater pits	Finished	45,000
IT Corporation	Louisiana AAP	Minden	LA	Munitions plant redwater lagoon	Finished	100,000
IT Corporation	Sikes Pits	Crosby	TX	Chemical waste disposal pits	Contracted	341,000
Kimmins	La Salle	La Salle	IL	PCB capacitor manufacturing	Contracted	69,000
Ogden	Confidential	Sacramento	CA	Town gas site	Contracted	22,500
Ogden	Swanson River	Kenai	AK	Oil pipeline compressor oil	Ongoing	80,000
Ogden	Stockton	Stockton	CA	Underground tank oil leak	Ongoing	16,000
O. H. Materials	Goose Bay	Goose Bay	Canada	PCBs	Ongoing	4,000
O. H. Materials	Gas station	Cocoa	FL	Petroleum tank leak	Finished	1,000
O. H. Materials	Rail yard		PA	Repetitive spills	Finished	1,500
O. H. Materials	Twin City AAP	New Brighton	MN	Munitions plant	Finished	2,000
O. H. Materials	Rail yard		PA	Diesel tank spill	Finished	1,300
O. H. Materials	Florida Steel	Indiantown	FL	Steel mill used oils	Finished	18,000
O. H. Materials	Rail yard	Cleveland	OH	Refueling station	Finished	1,500
Site Recl. Systems	Koch Chemical		KS	Tank bottoms	Contracted	700
Site Recl. Systems	Gulf Oil	Multiple sites	FL	Oil spills	Contracted	18,000
Site Recl. Systems	Sun Oil	Multiple sites		Oil spills	Contracted	
Soil Remediation Co.	Multiple sites	Multiple sites	SC	Gas and oil leaks/spills	Finished	3,000
Soiltech	Waukegan Harbor	Waukegan	IL	Marine motor manufacturing	Contracted	20,000
TDI Services	Chevron Refinery	El Segundo	CA	API sludges	Contracted	30,000
Thermodynamics Corp	S. Crop Services	Delray Beach	FL	Crop dusting operation	Finished	1,800
U.S. Waste Thermal Proc.	Gas station	Temecula	CA	Petroleum tank leak	Finished	1,000
U.S. Waste Thermal Proc.	Confidential		CA	Oil spills	Contracted	7,500
U.S. Waste Thermal Proc.	Confidential	San Bernadino	CA	Oil spills	Finished	540
Vertac Site Contractors	Vertac	Jacksonville	AR	Chemical manufacturing	Contracted	6,500
Vesta	Nyanza	Ashland	MA	Dye manufacturing	Finished	1,000
Vesta	Rocky Boy	Havre	MT	Wood treatment	Ongoing	1,800
Vesta	S. Crop Services	Delray Beach	FL	Crop dusting operation	Finished	1,800
Vesta	American Crossarm	Chehalis	WA	Wood treatment	Finished	900
Vesta	Fort A.P. Hill	Bowling Green	VA	Army base	finished	200
Westinghouse/Haztech	Peak Oil	Tampa	FL	Used oil recycling	Finished	7,000
Westinghouse/Haztech	La Salle	La Salle	IL	Transformer reconditioning	Finished	30,000
Weston	Revenue	Springfield	IL		Finished	1,000
Weston	Letterkenny Depot	Chambersburg	PA	Army depot	Finished	500
Weston	Tinker AFB	Oklahoma City	OK	Air Force base	Finished	1,000
Weston	Paxton Avenue	Chicago	IL	Waste lagoon	Ongoing	16,000
Weston	Lauder Salvage	Beardstown	IL	Metal scrap salvage	Finished	8,500

Table III. Equipment data.

Vendor	Site name	No. of units	Combustion equipment type	Thermal capacity (mm Btu/hr)	APC equipment type
AET	Valdez	1	Rotary kiln	20	
Canonie	Ottati & Goss	1	Asphalt kiln	55	Baghouse, carbon, scrubber
Canonie	Canon Bridgewater	1	Asphalt kiln	55	Baghouse, carbon, scrubber
Canonie	South Kearny	1	Asphalt kiln	55	Baghouse, carbon, scrubber
Canonie	McKin	1	Asphalt kiln	55	Baghouse, carbon, scrubber
Chemical Waste Mgt.	Confidential	1	High temperature indirect desorber		Condensation, carbon
Ensco	Union Carbide	1	Rotary kiln	35	Steam ejector scrubber
Ensco	Lenz Oil	1	Rotary kiln	35	Steam ejector scrubber
Ensco	Sydney Mines	1	Rotary kiln	35	Steam ejector scrubber
Ensco	NCBC	1	Rotary kiln	35	Steam ejector scrubber
Ensco	Bridgeport Rental	1	Rotary kiln	100	Steam ejector scrubber
Ensco	Smithville	1	Rotary kiln	35	Steam ejector scrubber
GDC engineering	Rubicon	1	Infrared conveyor furnace		Waterloo scrubber
Harmon	Bog Creek	1	Rotary kiln	82	Cyclone, baghouse, packed bed
Harmon	Confidential	1	Low temperature direct desorber	21	Baghouse
Harmon	Prentiss Creosote	1	Rotary kiln	82	Cyclone, baghouse, packed bed
IT Corporation	Motco	2	Rotary kiln	56	Hydrosonics tandem scrubber
IT Corporation	Cornhusker AAP	1	Rotary kiln	56	Hydrosonics tandem scrubber
IT Corporation	Louisiana AAP	1	Rotary kiln	56	Hydrosonics tandem scrubber
IT Corporation	Sikes Pits	2	Rotary kiln	56	Hydrosonics tandem scrubber
Kimmins	La Salle	1	Rotary kiln	100	Baghouse, packed bed
Ogden	Confidential	1	Circulating fluid bed	10	Baghouse
Ogden	Swanson River	1	Circulating fluid bed	10	Baghouse

Table III. Equipment data (continued).

Vendor	Site name	No. of units	Combustion equipment type	Thermal capacity (mm Btu/hr)	APC equipment type
Ogden	Stockton	1	Circulating fluid bed	10	Baghouse
O. H. Materials	Goose Bay	1	Infrared conveyor furnace	30	Venturi, packed bed
O. H. Materials	Gas station	1	Low temperature direct desorber	12	Venturi
O. H. Materials	Rail yard	1	Low temperature direct desorber	20	Cyclone, venturi
O. H. Materials	Twin city AAP	1	Infrared conveyor furnace	30	Venturi, packed bed
O. H. Materials	Rail yard	1	Low temperature direct desorber	20	Cyclone, venturi
O. H. Materials	Florida Steel	1	Infrared conveyor furnace	30	Venturi, packed bed
O. H. Materials	Rail yard	1	Low temperature direct desorber	20	Cyclone, venturi
Site Recl. Systems	Koch Chemical	1	Asphalt kiln	47	Baghouse
Site Recl. Systems	Gulf Oil	1	Asphalt kiln	25	Baghouse
Site Recl. Systems	Sun Oil	1	Asphalt kiln	25	Baghouse
Soil Remediation Co.	Multiple sites	1	Asphalt kiln	48	Cyclone, baghouse
Soiltech	Waukegan Harbor	1	High temperature indirect desorber	14	Baghouse, cyclone, scrubber
TDI Services	Chevron Refinery	1	High temperature indirect desorber		Condensation, carbon
Thermodynamics Corp	S. Crop Services	1	Rotary kiln	7	Wet scrubber
U.S. Waste Thermal Proc.	Gas station	1	Infrared conveyor furnace	10	Calvert scrubber
U.S. Waste Thermal Proc.	Confidential	1	Infrared conveyor furnace	10	Calvert scrubber
U.S. Waste Thermal Proc.	Confidential	1	Infrared conveyor furnace	10	Calvert scrubber
Vertac Site contractors	Vertac	1	Rotary kiln	35	Spray dryer, baghouse, scrubber
Vesta	Nyanza	1	Rotary kiln	8	Wet scrubber
Vesta	Rocky Boy	1	Rotary kiln	12	Wet scrubber
Vesta	S. Crop Services	1	Rotary kiln	12	Wet scrubber
Vesta	American Crossarm	1	Rotary kiln	12	Wet scrubber
Vesta	Fort A.P. Hill	1	Rotary kiln	12	Wet scrubber
Westinghouse/Haztech	Peak Oil	1	Infrared conveyor furnace	30	Wet scrubber
Westinghouse/Haztech	La Salle	1	Infrared conveyor furnace	30	Wet scrubber
Weston	Revenue	1	Low temperature indirect desorber	12	Baghouse
Weston	Letterkenny Depot	1	Low temperature indirect desorber	12	Afterburner
Weston	Tinker AFB	1	Low temperature indirect desorber	12	Baghouse, wet scrubber
Weston	Paxton Avenue	1	Rotary kiln	35	Baghouse, packed bed
Weston	Lauder Salvage	1	Rotary kiln	35	Baghouse, packed bed

Table IV. Performance data.

Vendor	Site name	Indicator compound	Contaminant concentration in treated soil (mg/kg)	Trial burn required	Particulate emissions (GR/DSCF @ 7% O_2)	RCRA permit	TSCA permit
AET	Valdez	Petroleum hydrocarbons					
Canonie	Ottati & Goss	Volatile organics	<0.2	Yes	<0.03	No	No
Canonie	Canon Bridgewater	Total VOC	<0.1	No		No	No
Canonie	South Kearny	Volatile organics		No		No	No
Canonie	McKin	Trichloroethylene	<0.1	Yes	<0.03	No	No
Chemical Waste Mgt.	Confidential	PCBs	<2.0				
Ensco	Union Carbide			Yes		Yes	
Ensco	Lenz Oil	Hydrocarbons	<5.0	Yes	.006		
Ensco	Sydney Mines	Hydrocarbons	<5.0	No			
Ensco	NCBC	Dioxin	<15 PPT	Yes	.017		
Ensco	Bridgeport Rental	PCBs		Yes			
Ensco	Smithville	PCBs		Yes			
GDC Engineering	Rubicon			Yes		No	No
Harmon	Bog Creek			Yes	0.015		No
Harmon	Confidential	Petroleum hydrocarbons	<100	No		No	No
Harmon	Prentiss Creosote	PAHs	<2	Yes	0.011	No	No
IT Corporation	Motco	PCBs		Yes		No	No
IT Corporation	Cornhusker AAP	Trinitrotoluene	<1.3	Yes	0.0017	No	No
IT Corporation	Louisiana AAP	Trinitrotoluene	<1.3	Yes		No	No
IT Corporation	Sikes Pits	Total PNAs	<100	Yes	<0.06	No	No
Kimmins	La Salle	PCBs	<2.0	Yes		No	No
Ogden	Confidential						
Ogden	Swanson River	PCBs	<0.1	Yes	<0.06	No	Yes
Ogden	Stockton	Total hydrocarbons	<1	Yes	<0.06	No	No
O. H. Materials	Goose Bay	PCBs		Yes		No	Yes
O. H. Materials	Gas station	Benzene, toluene, xylene	<0.1	Yes	0.011	No	No
O. H. Materials	Rail yard	Diesel oil	<100				
O. H. Materials	Twin City AAP	PCBs	<2	No		No	Yes
O. H. Materials	Rail yard	Diesel oil	<100				
O. H. Materials	Florida Steel	PCBs	<2	Yes	0.056	No	Yes

(Continued on next page).

Thermal Remediation Industry Information

Important findings from the contractor survey are summarized below:

- In general, the major problem in the Thermal Remediation Industry has been materials handling for different types of soils and complex wastes.
- Modified asphalt kilns are being used throughout the country as fixed regional treatment centers for gasoline and oil contaminated soils from gasoline stations, underground storage tank cleanups, and oil spills. These units are typically permitted under air permits. Early asphalt kiln installations did not include secondary combustion chambers. Recent installations, however, are incorporating this design feature.
- Ensco, Vesta and Harmon have installed oxygen augmented burners on their rotary kilns. Ensco is using this technology at the Bridgeport site, Vesta in Canada and Harmon at the Bog Creek site.
- Ogden Environmental Services has obtained approval from California to operate its mobile circulating bed combustor (CBC) as a fixed regional thermal treatment facility for oil contaminated soils. The CBC will be kept at Stockton, California where it is currently remediating a site contaminated with fuel oil.

Summary

Table I presents a summary of the current project status of the thermal remediation industry. Data in Table I shows that at least 39 full-scale thermal remediation projects have been completed or are in progress by 15 contractors. The estimated quantity of material that has or will be processed during these 39 projects *is* approximately 700,000 tons. There are an additional 15 contracted thermal remediation projects which will process an estimated quantity of 565,000 tons of contaminated material. The total of all projects is close to 1,300,000 tons.

Summaries of the contractor survey information are included in Tables II through IV. While these tables are considered to be a fairly complete compilation of the full-scale U.S. thermal remediation projects through January 1990, it is possible that additional work has been done which is not included.

While the use of thermal equipment to decontaminate soils is presently one of the highest cost cleanup options, it produces a soil with the lowest organic residuals and therefore the least future liability. As the Land Ban Restrictions require more types of waste to be treated and as cleanup criteria become more stringent, it is expected that thermal remediation will be used more extensively for decontaminating soils and sludges.

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Table IV. Performance data (continued).

Vendor	Site name	Indicator compound	Contaminant concentration in treated soil (mg/kg)	Trial burn required	Particulate emissions (GR/DSCF @ 7% O_2)	RCRA permit	TSCA permit
O. H. Materials	Rail yard	Petroleum hydrocarbons	<50	Yes	0.039	No	No
Site Recl. Systems	Koch Chemical	Toluene, xylene					
Site Recl. Systems	Gulf Oil	Benzene, toluene, xylene	<0.1	No		No	No
Site Recl. Systems	Sun Oil						
Soil Remediation Co.	Multiple sites	Petroleum hydrocarbons	<50			No	No
Soiltech	Waukegan Harbor	PCBs		Yes		No	No
TDI Services	Chevron Refinery		BDAT	No		No	No
Thermodynamics Corp	S. Crop Services	Pentachlorophenol	0.003	Yes	0.035	No	No
U.S. Waste Thermal Proc.	Gas station	Total hydrocarbons	<10	No	0.008	No	No
U.S. Waste Thermal Proc.	Confidential	Total hydrocarbons		No		No	No
U.S. Waste Thermal Proc.	Confidential	Total hydrocarbons	<10	No		No	No
Vertac Site Contractors	Vertac	Dioxins		Yes	<0.08	No	No
Vesta	Nyanza	Nitrobenzene		Yes	0.02	No	No
Vesta	Rocky Boy	Pentachlorophenol		Yes		No	No
Vesta	S. Crop Services	DDT	<0.2	Yes	0.03	No	No
Vesta	American Crossarm	Dioxin	<0.001	Yes	0.011	No	No
Vesta	Fort A. P. Hill	Dioxin	<0.001	Yes	0.02	No	No
Westinghoue/Haztech	Peak Oil	PCBs	<1	Yes	<0.08	No	No
Westinghoue/Haztech	La Salle	PCBs	<2	Yes	<0.08	No	No
Weston	Revenue	PAHs	<0.33	No		No	No
Weston	Letterkenny Depot	Benzene, toluene, xylene	<1	No		No	No
Weston	Tinker AFB	Trichloroethylene		No		No	No
Weston	Paxton Avenue	RCRA constituents		Yes		No	No
Weston	Lauder Salvage	PCBs	<2	Yes	0.02	No	Yes

United States Environmental Protection Agency	Office of Emergency and Remedial Response Washington, DC 20460	Office of Research and Development Cincinnati, OH 45268
Superfund	EPA/540/2-90/014	September 1990

EPA

Engineering Bulletin Mobile/Transportable Incineration Treatment

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants as a principal element." The Engineering Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial investigation scoping needs. Addenda will be issued periodically to update the original bulletins.

Abstract

Incineration treats organic contaminants in solids and liquids by subjecting them to temperatures typically greater than 1000°F in the presence of oxygen, which causes the volatilization, combustion, and destruction of these compounds. This bulletin describes mobile/transportable incineration systems that can be moved to and subsequently removed from Superfund and other hazardous waste sites. It does not address other thermal processes that operate at lower temperatures or those that operate at very high temperatures, such as a plasma arc. It is applicable to a wide range of organic wastes and is generally not used in treating inorganics and metals. Mobile/transportable incinerators exhibit essentially the same environmental performance as their stationary counterparts. To date, 49 of the 95 records of decision (RODs) designating thermal remedies at Superfund sites have selected onsite incineration as an integral part of a preferred treatment alternative. There are 22 commercial-scale units in operation [5]*. This bulletin provides information on the technology applicability, the types of residuals resulting from the use of the technology, the latest performance data, site requirements, the status of the technology, and where to go for further information.

Technology Applicability

Mobile/transportable incineration has been shown to be effective in treating soils, sediments, sludges, and liquids containing primarily organic contaminants such as halogenated and nonhalogenated volatiles and semivolatiles, polychlorinated biphenyls (PCBs), pesticides, dioxins/furans, organic cyanides, and organic corrosives. The process is applicable for the thermal treatment of a wide range of specific Resource Conservation and Recovery Act (RCRA) wastes and other hazardous waste matrices that include pesticides and herbicides, spent halogenated and nonhalogenated solvents, chlorinated phenol and chlorinated benzene manufacturing wastes, wood preservation and wastewater sludge, organic chemicals production residues, pesticides production residues, explosives manufacturing wastes, petroleum refining wastes, coke industry wastes, and organic chemicals residues [1] [2] [4] [6 through 11] [13].

Information on the physical and chemical characteristics of the waste matrix is necessary to assess the matrix's impact on waste preparation, handling, and feeding; incinerator type, performance, size, and cost; air pollution control (APC) type and size; and residue handling. Key physical parameters include waste matrix physical characteristics (type of matrix, physical form, handling properties, and particle size), moisture content, and heating value. Key chemical parameters include the type and concentration of organic compounds including PCBs and dioxins, inorganics (metals), halogens, sulfur, and phosphorous.

The effectiveness of mobile/transportable incineration on general contaminant groups for various matrices is shown in Table 1 [7, p. 9]. Examples of constituents within contaminant groups are provided in Reference 7, "Technology Screening Guide for Treatment of CERCLA Soils and Sludges." This table

* [reference number, page number]

Table 1
Effectiveness of Incineration on General Contaminant Groups for Soil, Sediment, Sludge, and Liquid

	Contaminant Groups	Soil/ Sediment	Sludge	Liquid
Organic	Halogenated volatiles	■	■	■
	Halogenated semivolatiles	■	■	■
	Nonhalogenated volatiles	■	■	■
	Nonhalogenated semivolatiles	■	■	■
	PCBs	■	■	■
	Pesticides (halogenated)	▼	■	■
	Dioxins/Furans	■	■	■
	Organic cyanides	▼	▼	▼
	Organic corrosives	▼	▼	▼
Inorganic	Volatile metals	❑	❑	❑
	Nonvolatile metals	❑	❑	❑
	Asbestos	❑	❑	❑
	Radioactive materials	❑	❑	❑
	Inorganic corrosives	❑	❑	❑
	Inorganic cyanides	▼	▼	▼
Reactive	Oxidizers	▼	▼	▼
	Reducers	▼	▼	▼

■ Demonstrated Effectiveness: Successful treatability test at some scale completed

▼ Potential Effectiveness: Expert opinion that technology will work

❑ No Expected Effectiveness: Expert opinion that technology will not work

is based on current available information or professional judgment when no information was available. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the treatment efficiency achieved will be acceptable at other sites. For the ratings used for this table, demonstrated effectiveness means that, at some scale, treatability was tested to show that the technology was effective for a particular contaminant and matrix. The ratings of potential effectiveness or no expected effectiveness are based upon expert judgment. Where potential effectiveness is indicated, the technology is believed capable of successfully treating the contaminant group in a particular matrix. When the technology is not applicable or will probably not work for a particular combination of contaminant group and matrix, a no-expected-effectiveness rating is given. Other sources of general observations and average removal efficiencies for different treatability groups are the Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions," (OSWER Directive 9347.3-06FS [13], and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions," (OSWER Directive 9347.3-07FS [14].

Limitations

Toxic metals such as arsenic, lead, mercury, cadmium, and chromium are not destroyed by combustion. As a result, some will be present in the ash while others are volatilized and released into the flue gas [1, pp. 3-6].

Alkali metals, such as sodium and potassium, can cause severe refractory attack and form a sticky, low-melting-point submicron particulate, which causes APC problems. A low feed stream concentration of sodium and potassium may be achieved through feed stock blending [1, pp. 3-11].

When PCBs and dioxins are present, higher temperatures and longer residence times may be required to destroy them to levels necessary to meet regulatory criteria [7, p. 34].

Moisture/water content of waste materials can create the need to co-incinerate these materials with higher BTU streams, or to use auxiliary fuels.

The heating value (BTU content) of the feed material affects feed capacity and fuel usage of the incinerator. In general, as the heating value of the feed increases, the feed capacity and fuel usage of the incinerator will decrease. Solid materials with high calorific values also may cause transient behaviors that further limit feed capacity [9, p. 4].

The matrix characteristics of the waste affect the pretreatment required and the capacity of the incinerator and can cause APC problems. Organic liquid wastes can be pumped to and then atomized in the incinerator combustion chamber. Aqueous liquids may be suitable for incineration if they contain a substantial amount of organic matter. However, because of the large energy demand for evaporation when treating large volumes of aqueous liquids, pretreatment to dewater the waste may be cost effective [1, pp. 3-14]. Also, if the organic content is low, other methods of treatment may be more economical. For the infrared incinerator, only solid and solid-like materials within a specific size and moisture content range can be processed because of the unique conveyor belt feed system within the unit.

Sandy soil is relatively easy to feed and generally requires no special handling procedures. Clay, which may be in large clumps, may require size reduction. Rocky soils usually require screening to remove oversize stones and boulders. The solids can then be fed by gravity, screw feeder, or ram-type feeder into the incinerator. Some types of solid waste may also require crushing, grinding, and/or shredding prior to incineration [1, pp. 3-17].

The form and structure of the waste feed can cause periodic jams in the feed and ash handling systems. Wooden pallets, metal drum closure rings, drum shards, plastics, trash, clothing, and mud can cause blockages if poorly prepared. Muddy soils can stick to waste processing equipment and plug the feed system [9, p. 8].

The particle size distribution of the ash generated from the waste can affect the amount of particulate carry-over from the combustion chamber to the rest of the system [9, p. 16].

Incineration of halogens, such as fluorine and chlorine, generates acid gases that can affect the capacity, the water removal and replacement rates that control total dissolved solids in the process water system, and the particulate emissions [9, p. 12]. The solutions used to neutralize these acid gases add to the cost of operating this technology.

Organic phosphorous compounds form phosphorous pentoxide, which attacks refractory material, causes slagging problems and APC problems. Slagging can be controlled by feed blending or operating at lower temperatures [1, pp. 3-10].

Technology Description

Figure 1 is a schematic of the mobile/transportable incineration process.

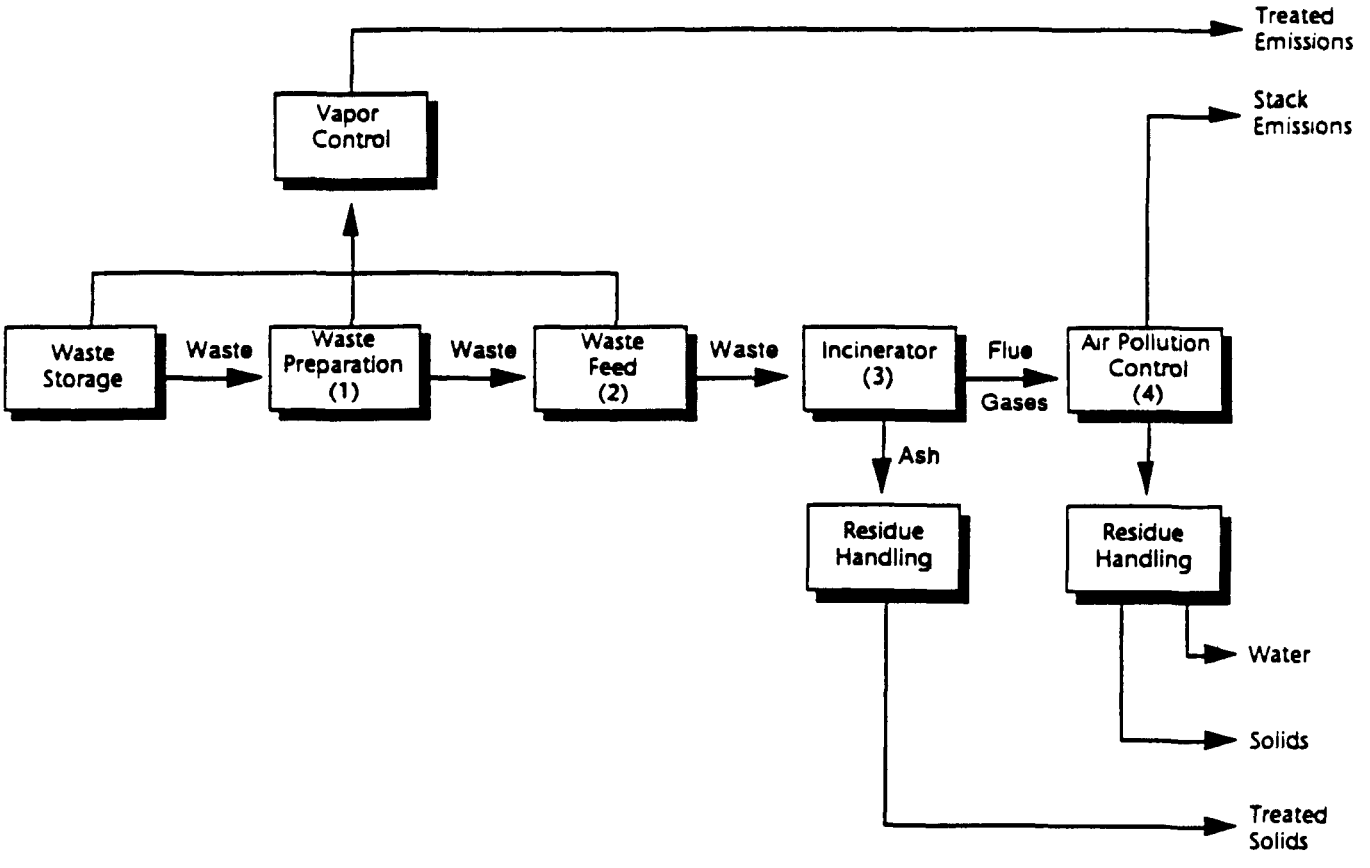
Waste preparation (1) includes excavation and/or moving the waste to the site. Depending on the requirements of the incinerator type for soils and solids, various equipment is used to obtain the necessary feed size. Blending is sometimes required to achieve a uniform feed size and moisture content or to dilute troublesome components [1, pp. 3-19].

The waste feed mechanism (2), which varies with the type of the incinerator, introduces the waste into the combustion system. The feed mechanism sets the requirements for waste preparation and is a potential source of problems in the actual operation of incinerators if not carefully designed [1, pp. 3-19].

Different incinerator designs (3) use different mechanisms to obtain the temperature at which the furnace is operated, the time during which the combustible material is subject to that temperature, and the turbulence required to ensure that all the combustible material is exposed to oxygen to ensure complete combustion. Three common types of incineration systems for treating contaminated soils are rotary kiln, circulating fluidized bed, and infrared.

The rotary kiln is a slightly inclined cylinder that rotates on its horizontal axis. Waste is fed into the high end of the rotary kiln and passes through the combustion chamber by gravity. A secondary combustion chamber (afterburner) further destroys unburned organics in the flue gases [7, p. 40].

Figure 1
Mobile/Transportable Incineration Process



Circulating fluidized bed incinerators use high air velocity to circulate and suspend the fuel/waste particles in a combustor loop. Flue gas is separated from heavier particles in a solids separation cyclone. Circulating fluidized beds do not require an afterburner [7, p. 35].

Infrared processing systems use electrical resistance heating elements or indirect fuel-fired radiant U-tubes to generate thermal radiation [1, pp. 4-5]. Waste is fed into the combustion chamber by a conveyor belt and exposed to the radiant heat. Exhaust gases pass through a secondary combustion chamber.

Offgases from the incinerator are treated by the APC equipment to remove particulates and capture and neutralize acids (4). Rotary kilns and infrared processing systems may require both external particulate control and acid gas scrubbing systems. Circulating fluidized beds do not require scrubbing systems because limestone can be added directly into the combustor loop but may require a system to remove particulates [1, pp. 4-11] [2, p. 32]. APC equipment that can be used include venturi scrubbers, wet electrostatic precipitators, baghouses, and packed scrubbers.

Process Residuals

Three major waste streams are generated by this technology: solids from the incinerator and APC system, water from the APC system, and emissions from the incinerator.

Ash and treated soil/solids from the incinerator combustion chamber may be contaminated with heavy metals. APC system solids, such as fly ash, may contain high concentrations of volatile metals. If these residues fail required leachate toxicity tests, they can be treated by a process such as stabilization/solidification and disposed of onsite or in an approved landfill [7, p. 126].

Liquid waste from the APC system may contain caustic, high chlorides, volatile metals, trace organics, metal particulates, and inorganic particulates. Treatment may require neutralization, chemical precipitation, reverse osmosis, settling, evaporation, filtration, or carbon adsorption before discharge [7, p. 127].

The flue gases from the incinerator are treated by APC systems such as electrostatic precipitators or venturi scrubbers before discharge through a stack.

Site Requirements

The site should be accessible by truck or rail and a graded/gravel area is required for setup of the system. Concrete pads may be required for some equipment (e.g., rotary kiln). For a typical 5 tons per hour commercial-scale unit, 2 to 5 acres are required for the overall system site including ancillary support [10, p. 25].

Standard 440V three-phase electrical service is needed. A continuous water supply must be available at the site. Auxiliary fuel for feed BTU improvement may be required.

Contaminated soils or other waste materials are hazardous and their handling requires that a site safety plan be developed to provide for personnel protection and special handling measures.

Various ancillary equipment may be required, such as liquid/sludge transfer and feed pumps, ash collection and solids handling equipment, personnel and maintenance facilities, and process-generated waste treatment equipment. In addition, a feed-materials staging area, a decontamination trailer, an ash handling area, water treatment facilities, and a parking area may be required [10, p. 24].

Proximity to a residential neighborhood will affect plant noise requirements and may result in more stringent emissions limitations on the incineration system.

Storage area and/or tanks for fuel, wastewater, and blending of waste feed materials may be needed.

No specific onsite analytical capabilities are necessary on a routine basis; however, depending on the site characteristics or a specific Federal, State, or local requirement, some analytical capability may be required.

Performance Data

More than any other technology, incineration is subject to a series of technology-specific regulations, including the following Federal requirements: the Clean Air Act 40 CFR 52.21 for air emissions; Toxic Substances Control Act (TSCA) 40 CFR 761.40 for PCB treatment and disposal; National Environmental Policy Act 40 CFR 6; RCRA 40 CFR 261/262/264/270 for hazardous waste generation, treatment performance, storage, and disposal standards; National Pollutant Discharge Elimination System 33 U.S.C. 1251 for discharge to surface waters; and the Noise Control Act P.L. 92-574. RCRA incineration standards have been proposed that address metal emissions and products of incomplete combustion. In addition, State requirements must be met if they are more stringent than the Federal requirements [1, p. 6-1].

All incineration operations conducted at CERCLA sites on hazardous waste must comply with substantive and defined Federal and State applicable or relevant and appropriate requirements (ARARs) at the site. A substantial body of trial burn results and other quality assured data exists to verify that incinerator operations remove and destroy organic contaminants from a variety of waste matrices to the parts per billion or even the parts per trillion level, while meeting stringent stack emission and water discharge requirements. The demonstrated treatment systems that will be discussed in the technology status section, therefore, can meet all the performance standards defined by the applicable Federal and State regulations on waste treatment, air emissions, discharge of process waters, and residue ash disposal [1, p. A-1] [4, p. 4] [10, p. 9].

RCRA Land Disposal Restrictions (LDRs) that require treatment of wastes to best demonstrated available technology (BDAT) levels prior to land disposal may sometimes be determined to be ARARs for CERCLA response actions. The solid

residuals from the incinerator may not meet required treatment levels in all cases. In cases where residues do not meet BDAT levels, mobile incineration still may be selected, in certain situations, for use at the site if a treatability variance establishing alternative treatment levels is obtained. EPA has made the treatability variance process available in order to ensure that LDRs do not unnecessarily restrict the use of alternative and innovative treatment technologies. Treatability variances may be justified for handling complex soil and debris matrices. The following guides describe when and how to seek a treatability variance for soil and debris: Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions," (OSWER Directive 9347.3-06FS) [13] and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions," (OSWER Directive 9347.3-07FS) [14].

Technology Status

To date, 49 of the 95 RODs designating thermal remedies at Superfund sites have selected onsite incineration as an integral part of a preferred treatment alternative.

Table 2 lists the site experience of the various mobile/transportable incinerator systems. It includes information on the incinerator type/size, the site size, location, and contaminant source or waste type treated [5] [3, p. 80] [8, p. 74].

The cost of incineration includes fixed and operational costs. Fixed costs include site preparation, permitting, and mobilization/demobilization. Operational costs such as labor, utilities, and fuel are dependent on the type of waste treated and the size of the site. Figure 2 gives an estimate of the total cost for incinerator systems based on site size [12, pp. 1-3]. Superfund sites contaminated with only volatile organic compounds can have even lower costs for thermal treatment then the costs shown in Figure 2.

EPA Contact

Technology-specific questions regarding mobile/transportable incineration may be directed to Donald A. Oberacker, U.S. EPA Risk Reduction Engineering Laboratory, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, telephone: FTS 684-7510 or (513) 569-7510.

Table 2.
Technology Status

Treatment System/ Vendor	*Thermal Capacity (MM BTU/Hr)*	*Experience*		
		Site, Location	*Waste Volume (tons)*	*Contaminant Source or Waste Type*
Rotary Kiln *Ensco*	35	Sydney Mines, Valrico, FL[▲]	10,000	Waste oil
		Lenz Oil NPL Site, Lemont, IL[▲]	26,000	Hydrocarbon - sludge/solid/liquid
		Naval Construction Battalion Center (NCBC), Gulfport, MS	22,000	Dioxin/soil
		Union Carbide, Seadrift, TX*	N/A	Chemical manufacturing
		Smithiville, Canada*	7,000	PCB transformer leaks
	100	Bridgeport Rental, Bridgeport, NJ*[▲]	100,000	Used oil recycling
Rotary Kiln *IT*	56	Cornhusker Army Ammunition Plant (CAAP), Grand Island, NE[▲]	45,000	Munitions plant redwater pits
		Louisiana Army Ammunition Plant (LAAP), Shreveport, LA*[▲]	100,000	Munitions plant redwater lagoon
		Motco, Texas City, TX*[▲]	80,000	Styrene tar disposal pits
Rotary Kiln *Vesta*	8	Fairway Six Site, Aberdeen, NC	50	Pesticide dump
	12	Fort A.P. Hill, Bowling Green, VA	200	Army base
		Nyanza/Nyacol Site, Ashland, MA[▲]	1,000	Dye manufacturing
		Southern Crop Services Site Delray Beach, FL	1,500	Crop dusting operation
		American Crossarm & Conduit Site Chehalis, WA[▲]	900	Wood treatment
		Rocky Boy, Havre, MT*	1,800	Wood treatment

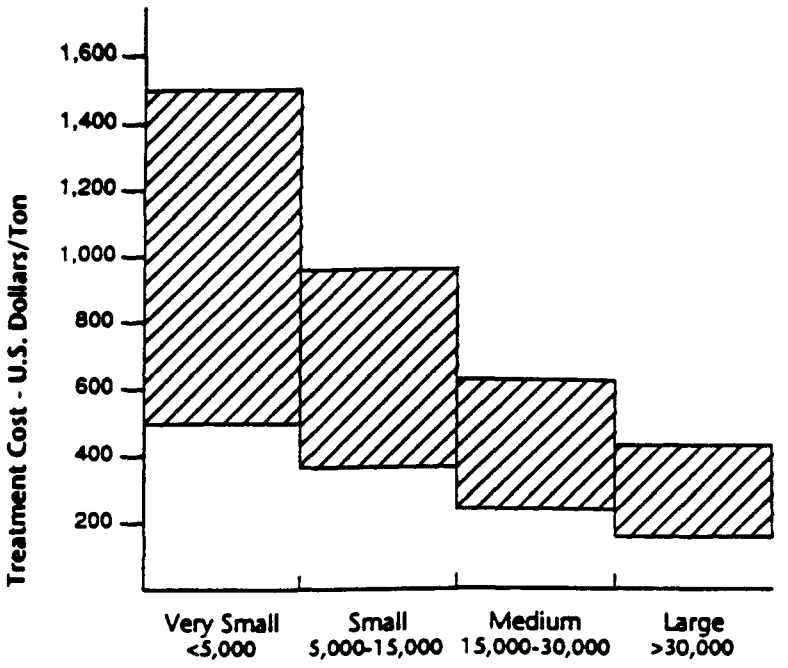
NA - Not available * Contracted, others completed ▲ Superfund Site [Source: References 3, 5, 8]

Table 2
Technology Status (Continued)

Treatment System/ Vendor	*Thermal Capacity (MM BTU/Hr)*	*Experience*		
		Site, Location	*Waste Volume (tons)*	*Contaminant Source or Waste Type*
Rotary Kiln *Weston*	35	Lauder Salvage, Beardstown, IL Paxton Ave., Chicago, IL*	8,500 16,000	Metal scrap salvage Waste lagoon
Rotary Kiln *AET*	20	Valdez, AK	NA	Crude oil spill
Rotary Kiln *Boliden*	40	Oak Creek, WI	50,000	Dye manufacturing
Rotary Kiln *Harmon*	82	Prentis Creosote & Forest Products Prentis, MS Bog Creek, Howell Township, NJ▲	9,200 22,500	Creosote/soil Organics
Rotary Kiln *Bell*	30	Bell Lumber&Pole, New Brighton, MN▲	21,000	Wood treatment
Rotary Kiln *Kimmins*	100	Lasalle, IL*▲	69,000	PCB capacitor manufacturing
Rotary Kiln *USEPA*	10	Denney Farm, MO	6,250	Dioxin Soils
Rotary Kiln *Vertac*	35	Vertac, Jacksonville, AR*▲	6,500	Chemical manufacturing
Shirco Infrared *Haztech*	30	Peak Oil, Tampa, FL▲ Lasalle, IL▲	7,000 30,000	Used oil recycling, PCBs/Lead Transformer reconditioning
Shirco Infrared *GDC Engr.*	NA	Rubicon, Geismar, LA*	52,000	Chemical manufacturing
Shirco Infrared *OH Materials*	30	Florida Steel, Indiantown, FL▲ Twin City AAP, New Brighton, MN Goosebay, Canada	18,000 2,000 4,000	Steel mill used oils Munitions plant PCBs
	12	Gas Station Site, Cocoa, FL	1,000	Petroleum tank leak
Shirco Infrared *U.S. Waste*	10	Private Site, San Bernadino, CA	5,400	Hydrocarbons
Circulating Bed Combustor *Ogden*	10	Arco Swanson River Field Kenai, AK* Stockton, CA*	80,000 16,000	Oil pipeline compressor oil Underground tank oil leak

NA - Not available * Contracted, others completed ▲Superfund Site [Source: References 3, 5, 8]

Figure 2
Effect of Site Size on Incineration Costs



Source: The Hazardous Waste Consultant [12, pp. 1-3]

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12. McCoy and Associates, Inc., The Hazardous Waste Consultant, Volume 7, Issue 3, 1989.
13. Superfund LDR Guide #6A: Obtaining a Soil and Debris Treatability Variance for Remedial Actions. OSWER Directive 9347.3-06FS, U.S. Environmental Protection Agency, 1989.
14. Superfund LDR Guide #6B: Obtaining a Soil and Debris Treatability Variance for Removal Actions. OSWER Directive 9347.3-07FS, U.S. Environmental Protection Agency, 1989.

2.14 KEY REFERENCE LIST - INCINERATION

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NOTE: EPA Headquarters Hazardous Waste Collection contains 276 references on incineration. This collection is accessed through EPA regional libraries.

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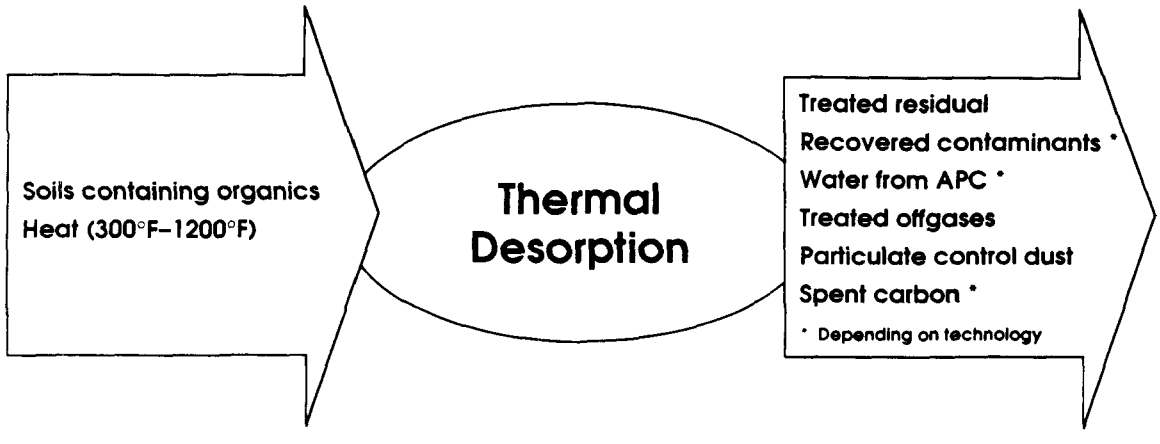
3.0 THERMAL DESORPTION

3.1 TECHNOLOGY DESCRIPTION

Thermal desorption technologies consist of a wide variety of processes that vaporize volatile and semi-volatile organics from soil and sludge. The processes are planned and designed to avoid combustion of the contaminants in the primary unit, resulting in several advantages. After desorption, the volatilized organics may be subsequently treated in an afterburner or condensed for reuse or destruction. The types of air pollution control equipment (APC) needed to treat the exhaust gases will vary depending on the technology and the nature of the contaminated media. Dust and particulates may be controlled with cyclones, baghouses or venturi scrubbers; small amounts of acid vapor may require scrubbing; and residual organics may be condensed and/or captured in activated carbon adsorption units.

Although there are no generally accepted definitions for grouping the different types of thermal desorption, the following three terms may be used to describe the different processes:

Directly heated desorption
Indirectly heated desorption
In situ steam extraction



3.1.1 Directly Heated Desorption

Direct-fired systems use a fuel burner as a heat source which may be either internal or external to the primary soil-heating chamber. Internally fired units resemble rotary kilns, operate at temperatures of less that 800°F (426°C), and have generally been limited to use for the treatment of non-chlorinated organics such as petroleum spills. Exhaust gases from the rotating cylinder pass through a dust-collection system prior to secondary combustion. OH Materials, Inc. operates a low temperature direct-fired desorber. Canonie Environmental has a low temperature thermal aeration system, which consists of a rotating dryer that heats incoming air from 300 to 600°F (148 to 315°C) by an external flame. The system forces heated air counter-current to the flow of soils in a rotary drum dryer. The system can be used for chlorinated wastes with carbon adsorption recovery of the treated organics.

3.1.2 Indirectly Heated Desorption

Indirectly heated systems transfer heat through metal surfaces to the waste. Indirect heating produces a lower volume of exhaust gas which results in a low loading for the exhaust-gas treatment and air-pollution-control systems. This also helps to control particulate carry-over. Vaporized contaminants are removed from the thermal processor using a sweep gas with low oxygen content to prevent oxidation (combustion and explosion). Desorbed organics may be condensed and/or removed by carbon adsorption. These systems can be further characterized by their operating range, with approximately 600°F serving as a breakpoint. Systems operating at less than this temperature are designed for volatiles and systems above this temperature are intended for semi-volatile organics and PCBs. It should be noted, however, that semi-volatile organics may also be removed at the lower operating temperature range (below their boiling point) as a result of stripping in the presence of water vapor and/or volatiles.

Examples of developers of this technology at the lower operating temperature range include Weston Services, Inc. and the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). These units consist of a low-temperature thermal-stripping process, which uses a hollow-screw mixer that is filled with hot oil to heat the soil to approximately 450°F (232°C).

Two examples of technologies at higher temperatures (>600°F)(315°C) are Chemical Waste Management's X*TRAX System and SoilTech's AOSTRA Taciuk Processor. Both processes recover contaminants for subsequent recycling or destruction. The X*TRAX system uses a nitrogen atmosphere to keep the process oxygen free. Waste is treated in an indirectly heated rotating dryer at temperatures ranging from 600 to 900°F (315 to 482°C). The volatilized organics are carried to a gas treatment system that condenses and recovers the contaminants. The Taciuk

process consists of a preheating chamber which operates at 300 to 600°F causing the vaporization of water and light hydrocarbons. A second stage involves heating at temperatures up to 1,150°F to cause vaporization and pyrolysis of heavy hydrocarbons. The desorbed hydrocarbons are then recovered in a condenser.

3.1.3 In Situ Steam Extraction

This process uses hollow-stem drills to inject steam and hot air into the ground. Volatile organics are stripped from the soil (or ground water) and collected in a shroud at the surface. The technology is especially applicable for volatile contamination near the surface (where vacuum extraction is less effective). Although not generally applicable for semivolatiles, some removal may take place. Toxic Treatments (USA) has used their unit to treat soil at a state Superfund site. Steam (at 450°F) (232°C) and hot air (at 300°F) (148°C) are injected through counter rotating drills up to 30 feet in depth. Volatile contaminants and water vapor are collected and removed from the off-gas stream by condensation.

3.2 TECHNOLOGY STATUS

- This technology has been selected for 17 Superfund sites.
- Three PRP sites in Region I have been remediated by Canonie Engineering.

3.3 APPLICATION

- Boiling points for selected compounds are given in Exhibit 4. These are given for comparative purposes and most wastes will require treatability studies to confirm removal levels. Removal efficiencies may vary widely for similar soils.
- Thermal desorption is appropriate for both high and low concentrations of contaminants.
- See the article on Status of Thermal Remediation in the chapter on Incineration (Chapter 2.0).

3.4 TECHNOLOGY STRENGTHS

- Lower temperatures eliminate volatilization of some metal compounds (lead, cadmium, copper, and zinc)
- These processes operate at lower temperatures than incineration and so use less fuel.

- Concerns with products of incomplete combustion are eliminated by avoiding combustion in the primary desorbing unit.
- The technology has the ability to separate and recover concentrated contaminants which may then be taken off-site for treatment.
- Decontaminated soil still retains some organics and soil properties. It is not ash.

3.5 TECHNOLOGY LIMITATIONS

- The technology is not appropriate for inorganic contaminants.
- Although thermal desorbers operate at much lower temperatures than incinerators, some metals (i.e., mercury, arsenic) may volatilize during treatment.

3.6 POTENTIAL MATERIALS HANDLING REQUIREMENTS

- Excavation is required for desorber units.
- Dewatering may be necessary to achieve acceptable soil moisture content. (The cost of desorption increases as the moisture content increases.)
- The material must be screened to remove oversized particles.
- Size reduction may be needed to achieve feed size required by the equipment.
- The pH may be adjusted to achieve a pH between 5 and 11.

3.7 WASTE CHARACTERISTICS AFFECTING PERFORMANCE

- Temperature and residence time are the primary factors affecting performance.
- Wastes with high moisture content significantly increase fuel usage.
- Fine silt and clay may result in greater dust loading to the downstream air-pollution-control equipment, especially for directly heated systems.
- The volatility of the targeted waste constituents will be the primary factor that affects treatment performance. A good indicator of volatility is the pure component boiling point (see Exhibit 4). It is important to recognize that almost all hazardous wastes are mixtures of various organic constituents (both hazardous and non-hazardous) and these other constituents often have a significant impact on the actual removal of the specific compound from that matrix. Removal may be achieved at temperatures below the boiling point.

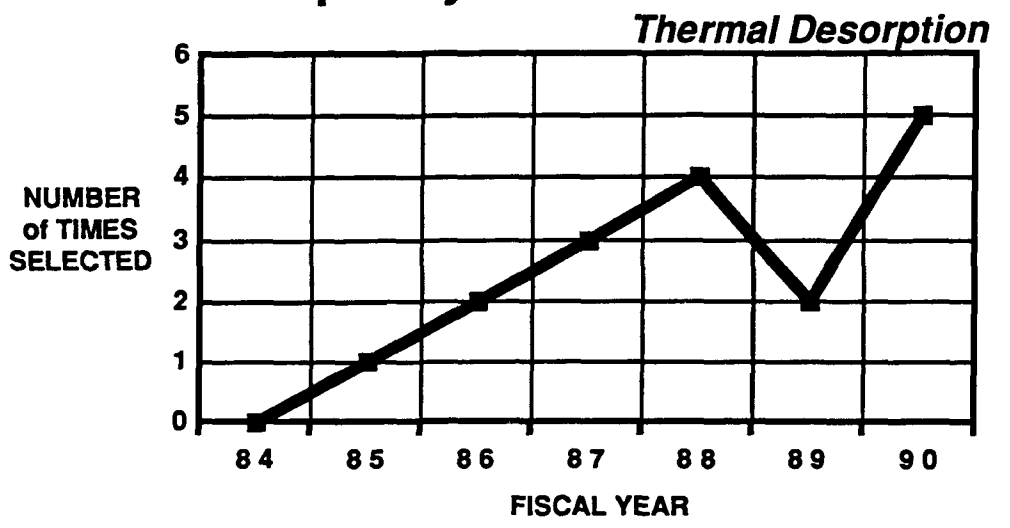
3.8 EXHIBIT 1 - WASTE CHARACTERISTIC TABLE

Waste Type: Soils and Sludges
Technology: Low Temperature Thermal Stripping

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Presence of: • Metals • Inorganics • Less volatile organics	Some process effective only for highly volatile organics (Henry's Law Constant >3 x 10^{-5} atm-m^3/mole). XTRAX system can treat organics with boiling points up to about 800°F (426°C)	Analysis for priority pollutants
pH <5, >11	Corrosive effect on system components	pH analysis
Presence of mercury (Hg)	Boiling point of mercury 670°F (356°C) close to operating temperature for process 212 to 572°F (100 to 300°C).	Analysis for mercury
Unfavorable soil characteristics:		
• High percent of clay or silt	Fugitive dust emissions during handling.	Grain size analysis
• Tightly aggregated soil or hardpan	Incomplete devolatilization during heating.	Soil sampling and mapping
• Rocky soil or glacial till	Rock fragments interfere with processing.	Soil mapping
• High moisture content	High energy input required. Dewatering may be required as pretreatment.	Soil moisture content

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

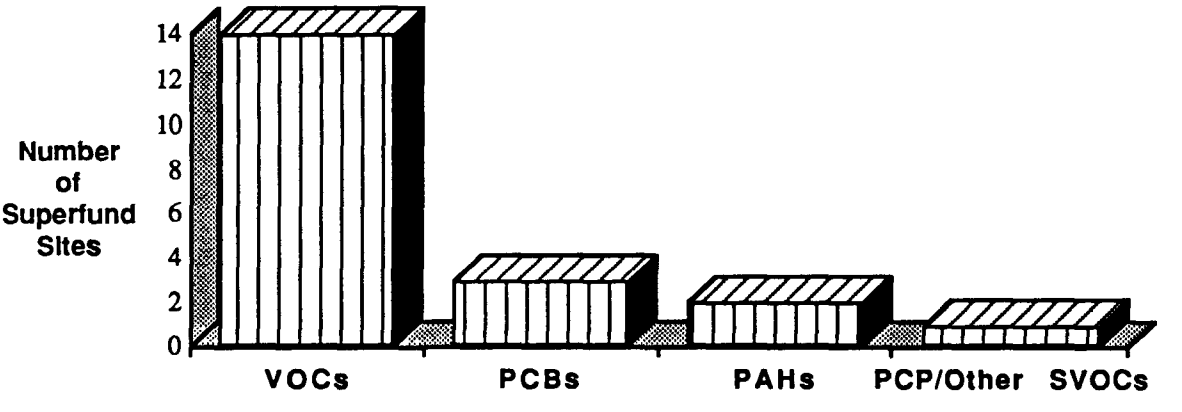
Selection Frequency*



* *Data derived from 1982 - 1990 Records of Decision (RODs) and anticipated design and construction activities.*

September 1991

Contaminants Treated By Thermal Desorption



* *Data derived from 1982 – 1990 Records of Decision (RODs) and anticipated design and construction activities. At some sites, the treatment is for more than one major contaminant.*

Thermal Desorption

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
1	Cannon Engineering/ Bridgewater, MA (03/31/88)	Thermal Aeration	Chemical Waste Handling, Storage, & Incineration Facility	Soil (11,330 cy)	VOCs (Benzene, TCE, and Vinyl Chloride)	Project completed; Operational 5/90 - 10/90	PRP Lead; Canonie Engineering	Dan Coughlin 617-573-9620 FTS 833-9620
1	McKin, ME* (07/22/85)	Thermal Aeration	Waste Storage, Transfer, Disposal Facility	Soil (11,456 cy)	VOCs (TCE, BTX)	Project completed; Operational 7/86 - 2/87	PRP Lead; Canonie Engineering	Sheila Eckman 617-573-5784 FTS 833-1784
1	Ottati & Goss, NH (01/16/87)	Thermal Aeration	Drum Recondition-ing Facility	Soil (16,000 cy)	VOCs (TCE, PCE, 1,2-DCA, and Benzene)	Project completed; Operational 6/89 - 9/89	PRP Lead; Canonie Engineering	Stephen Calder 617-573-9626 FTS 833-1626
1	Re-Solve, MA* (09/24/87) Also see Dechlorination	Rotary Thermal X*TRAX® Desorber (Dechlorination of residues)	Chemical Reclamation Facility	Soil (22,500 cy)	PCBs	Predesign; Pilot test planned for Fall '91; Design completion planned 1993	PRP Lead/ Mixed Funding; Chemical Waste Management, Inc.	Lorenzo Thantu 617-223-5500 FTS 833-1500
2	American Thermostat, NY (06/29/90)	Thermal Desorption	Thermostat Manufacturing	Soil (6,500 cy), Sediments (300 cy)	VOCs (PCE, TCE, DCE, and Vinyl Chloride)	In design; Design completion planned Spring '92	Fund Lead	Christos Tsiamis 212-264-5713 FTS 264-5713
2	Caldwell Trucking, NJ,* 02 (09/25/86)	Low Temperature Vaporization	Unpermitted Septic Waste Facility	Soil (20,000 cy)	VOCs (TCE, PCE, and TCA)	In design; Design completion planned Spring '92	Fund Lead	Ed Finnerty 212-264-3555 FTS 264-3555

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Thermal Desorption

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
2	Claremont Polychemical, NY (09/28/90)	Thermal Desorption	Chemical Facility	Soil (1,600 cy)	DDT, DDD, DDE, VOCs (DCE, PCE, TCE, and Toluene), SVOCs [Benzoic acid, Bis(2-ethylhexyl)phthalate, Butyl benzyl phthalate, Di-n-butyl phthalate, Naphthalene, and PCP], and PAHs (Benzo(a)pyrene)	In design; Design completion planned Winter '92	Fund Lead; USACE	Carlos R. Ramos 212-264-5636 FTS 264-5636
2	Fulton Terminals, NY (09/29/89)	Low Temperature Thermal Treatment	Former Waste Tank Farm	Soil (4,000 cy)	VOCs (Xylene, Styrene, TCE, Ethylbenzene, Toluene)	Predesign	PRP Lead	Christos Tsiamis 212-264-5713 FTS 264-5713
2	Marathon Battery, NY* (09/30/88)	Enhanced Volatilization	Former Battery Manufacturer	Soil (85,000 cy)	VOCs (PCE, Toluene, and TCE)	Predesign	Fund Lead	Pam Tames 212-264-1036 FTS 264-1036
2	Metaltec/Aerosystems, NJ (06/30/86)	Low Temperature Thermal Treatment	Metal Manufacturing	Soil (9,000 cy)	VOCs (TCE)	In design; Design completion planned Summer '91	Fund Lead; USACE	Jim Baly (USACE) 816-426-5221
2	Reich Farms, NJ (09/30/88)	Enhanced Volatilization	Uncontrolled Waste Disposal	Soil (1,120 cy)	VOCs and Semivolatiles	Pilot studies planned for early '92; design completion planned: Fall '92	PRP Lead	Gary Adamkiewicz 212-264-7592 FTS 264-7592
2	Sarney Farm, NY (09/27/90)	Low Temperature Thermal Treatment	Industrial and Municipal Landfill	Soil (2,365 cy)	VOCs (Benzene, Butanone, Chloroform, Methylpentanone, TCE, and Toluene)	Predesign; Design completion planned: Spring '93	Fund Lead	Kevin Willis 212-264-8777 FTS 264-8777

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Thermal Desorption

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
2	Waldick Aerospace Devices, NJ* (09/29/87)	Low Temperature Thermal Treatment	Manufacturing and Electroplating of Plane Parts	Soil (2,000 cy)	VOCs (TCE and PCE)	In design; Design completion planned October '91	Fund Lead	USACE Contracts Technical Issues: William McFarland (816) 426-5805 Contract Issues: Susan Anderson (816) 426-7424
4	Wamchem, SC* (06/30/88)	Low Temperature Thermal Treatment	Former Dye Manufacturing Plant	Soil (2,000 cy)	VOCs (BTX)	In design; Design completion planned Fall '91	PRP Lead	George Reedy 404-347-7791 FTS 257-7791
5	Outboard Marine/Waukegan Harbor, IL* (03/31/89)	Low Temperature Thermal Extraction (Taciuk Process)	Marine Products Manufacturing	Soil, Sediments (16,000 cy combined)	PCBs	In design; Design completion planned Fall '94	PRP Lead; Canonie Engineering	Cindy Nolan 312-886-0400 FTS 886-0400
5	University of Minnesota, MN (06/11/90)	Thermal Desorption (Fume Incineration of PCB Vapors)	University Wastes	Soil (6,300 cy), Debris (160 cy)	PCBs	In design; Design completion planned Fall '92	PRP Lead-State Oversight	Darrell Owens 312-886-7089 FTS 886-4089 David Douglas (MN) 612-296-7818
8	Martin Marietta (Denver Aerospace), CO* (09/24/90) See also Vacuum Extraction	Low Temperature Thermal Treatment	Aerospace Equipment Manufacturer	Soil (24,400 cy)	VOCs (TCE)	Predesign	State Lead (under RCRA Corrective Action Authority)	George Dancik 303-293-1506 FTS 330-1506

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

3.11 EXHIBIT 4 - BOILING POINTS OF SELECTED COMPOUNDS

Chemical Name	Boiling Point °F	Boiling Point (°C)
$BeCl_2$	7,052	(3,900)
Uranium and Compounds	6,904	(3,818)
Iron	4,982	(2,750)
$FeCl_2$	1,238	(670)
$FeCl_3$	599	(315)
Nickel	4,949	(2,732)
Chromium	4,842	(2,672)
CrO_2Cl_2	243	(117)
Copper	4,653	(2,567)
CuCl	2,491	(1,366)
$CuCl_2$	1,819	(993)
Chromium, hexavalent	4,500	(2,482)
Manganese and Compounds	3,564	(1,962)
Lead (Pb)	3,171	(1,744)
$PbCl_2$	1,742	(950)
Barium	2,084	(1,140)
BaO	3,632	(2,000)
Zinc and Compounds	1,665	(907)
ZnO_2	3,272	(1800)
$ZnCl_2$	1,350	(732)
Cadmium	1,409	(765)
CdO	1,652-1,832	(900-1,000)
$CdCl_2$	1,760	(960)
$SnCl_2$	1,153	(623)
Arsenic and Compounds	1,135	(613)
AS_2O_3	379	(193)
2,3,7,8-dioxin	932-1,500	(500-800)
Mercury	675	(357)
HgCL	575	(302)
Phenanthrene	644	(340)
ScO_2	603	(317)
Pentachlorophenol	588	(309)
Fluorene	559	(293)
Lindane	550	(288)
Polychlorinated biphenyls	512	(267+)
Pyrene	500	(260)
DDT	500	(260)
Methanol	360	(182)
Styrene	293	(145)
Xylene	280	(138)
Ethylbenzene	277	(136)
Chlorobenzene	270	(132)
Tetrachloroethane	264-295	(129-146)
1,1,2,2-tetrachloroethane	295	(146)
Tetrachloroethene	250	(121)
1,1,2-trichloroethane	235	(113)
Toluene	232	(111)

3.11 EXHIBIT 4 - BOILING POINTS OF SELECTED COMPOUNDS - (Continued)

Chemical Name	Boiling Point °F	(°C)
Trichloroethylene (TCE)	189	(87)
1,2-dichloroethane	183	(84)
Methyl ethyl ketone	176	(80)
Benzene	176	(80)
Carbon tetrachloride	171	(77)
1,1,1-trichloroethane	165	(74)
Chloroform	142	(61)
Cis-1,2-dichloroethylene	140	(60)
1,1-dichloroethane	135	(57)
Acetone	133	(56)
1,2-trans-dichloroethylene	118	(48)
Methylene chloride	106	(41)
1,1-dichloroethene	90	(32)
Cyanides (for HCN)	80	(27)
Naphthalene	70	(21)
Vinyl chloride	7	(-13.9)

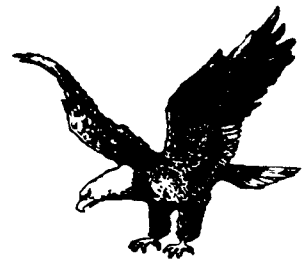
[a] Boiling point is for the pure chemical itself and may not reflect that for the various compounds.
[b] Sublimates.
[c] Decomposes.

US Army Corps of Engineers

USATHAMA

U.S. Army Toxic and Hazardous Materials Agency

Aberdeen Proving Ground, Maryland 21010-5401



THE LOW TEMPERATURE THERMAL STRIPPING PROCESS

Some of the Army's past waste disposal practices have resulted in soil contaminated with cleaning solvents and fuels commonly called VOCs, or Volatile Organic Compounds. Current methods to treat this soil contamination include incineration, disposal at a landfill or hazardous waste disposal facility and in situ volatilization. The Army has devised a fourth way, with a system that expends less energy than an incinerator and is cheaper to run.

The process, Low Temperature Thermal Stripping, or LTTS, has been developed and demonstrated by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), a Field Operating Agency for the U.S. Army Corps of Engineers, Aberdeen Proving Ground, Md.

Pilot and field tests during the past few years have proven the success of the LTTS as another option for cleaning up VOC-contaminated soil. The U.S. Army Corps of Engineers Waterways Experiment Station (WES), Vicksburg, Miss. is now accepting soil samples for pre-screening to determine the extent to which this technology is able to remove VOCs from different soil types.

WHAT ARE VOCs?

VOCs are compounds which volatilize, or turn into gas, at low temperatures. VOCs commonly found at Army installations are trichloroethylene (TCE), dichloroethylene, diesel fuel, methyl ethyl ketone (MEK), tetrachloroethylene, cleaning solvents and aviation fuel. VOCs are generally found wherever solvents and fuels were handled, such as fire training pits, burn pits, spill sites, and lagoons. VOCs in soil pose the risk of the contaminants seeping into drinking water supplies. If the concentration of VOCs in the soil is high and the soil is left untreated, VOC levels in drinking water may exceed drinking water limits if the ground water is used as source of drinking water.

WHY USE THE LTTS PROCESS ?

Incineration is a successful process for eliminating VOC contamination in soil. In the incineration process, soil is placed in a kiln, heated by fuel to temperatures ranging from 1000 to 2000 degrees Fahrenheit. The gases in the soil are driven off and then are secondarily burned in an afterburner, which is usually run at a slightly higher temperature than the kiln, completing the VOC destruction. The vapors pass through a scrubber system, before being released into the atmosphere.

Incineration, however, is a costly process. The Army's experience with certain types of organic contaminants in soil resulted in costs of approximately $300 per ton of soil. The LTTS process is expected to cut costs by more than 50 percent.

In situ or "in place" volatilization is an alternate method to LTTS that uses a vacuum extraction system to remove the VOCs at the site. In this system, venting pipes are placed in the ground at the contaminated site and air draws the VOCs up the pipes and into a treatment system. The cost of this treatment is about $50 per ton of soil. However, there are more limitations to the use of this process. The contaminated soil cannot be very wet and not all VOC-contaminated soil is treatable with in situ volatilization, particularly silty and clayey soils with low permeabilities.

HOW DOES THE LTTS PROCESS WORK?

Contaminated soil is fed through an opening at the top of the system, called the soil feed hopper. The soil falls into the main part of the system, or thermal processor. The thermal processor consists of two separate but identical units, each containing four large, hollow screws, eighteen inches in diameter, twenty feet long. As the screws turn, they churn the soil, breaking it up and pushing it from the feed end of the processor to the discharge end. In the meantime, hot oil is pumped through the inside of the screws. The constant churning of the soil and movement of hot oil up and down the length of the screws heat the soil and volatilizes the VOCs. Additional heat is provided by the walls of the processor, called the trough jacket, which also contains flowing hot oil. The thermal processor heats up to a maximum of about 650 degrees Fahrenheit.

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Once the VOCs are vaporized, they flow through piping into a burner or other means of treatment, such as a scrubber or carbon adsorption system. The VOC-free airstream then passes through a discharge stack monitored for VOCs.

In the meantime, the soil which is now virtually VOC-free, falls into the discharge end of the processor, where it can be put back into the excavation area.

WHAT HAVE PREVIOUS DEMONSTRATIONS CONCLUDED?

The results of the pilot and field tests showed the following for the particular soils and VOCs treated

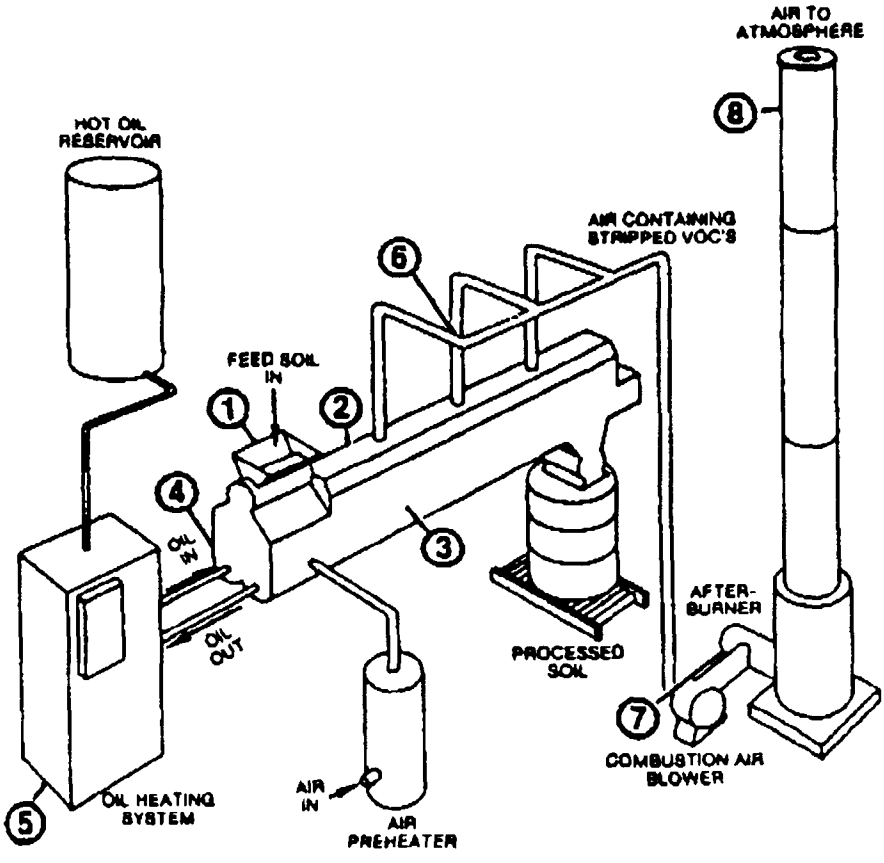
- More than 99 percent of the VOCs were removed from the soil;
- The process equipment available is capable of treating at least 10 tons of contaminated soil per hour; and
- There was a 99.99 percent Destruction and Removal Efficiency in the afterburner incineration step.

WHAT NEXT?

In coordination with USATHAMA, WES is establishing a bench-scale capability for screening contaminated soils to determine how well they can be treated by LTTS. The target date for having this capability is set for October 15, 1990. Federal agencies interested in determining the feasibility of using this technology for their site may send soil samples to WES for screening. The work will be performed on a cost-reimbursable basis. The results will be published in a report discussing the results of the soil samples that were used.

WHO DO I CONTACT?

Federal agencies interested in sending soil samples for pre-screening should contact Mr. Daniel Averett, WES, at (601) 634-3959. For more information on the technical aspects of the LTTS, contact CPT Craig A. Myler, USATHAMA, at (301) 671-2054.



Schematic diagram of the low temperature thermal stripping pilot system: (1) soil feed hopper, (2) thermal processor, (3) hollow screw conveyor with hot fluid flowing inside, (4) trough jacket, (5) oil heating system, (6) off-gas emission monitoring, (7) afterburner, and (8) stack testing for VOC, particulates, and HCl.

SITE Technology Profile

DEMONSTRATION PROGRAM

CHEMICAL WASTE MANAGEMENT (X*TRAX™ Low-Temperature Thermal Desorption)

TECHNOLOGY DESCRIPTION:

The X*TRAX™ technology is a low-temperature (200 to 900° F) thermal separation process designed to remove organic contaminants from soils, sludges, and other solid media (Figure 1). It is not an incinerator or a pyrolysis system. Chemical oxidation and reactions are not encouraged, and no combustion byproducts are formed. The organic contaminants are removed as a condensed high BTU liquid, which must then be either destroyed in a permitted incinerator or used as a supplemental fuel. Because of lower operating temperatures and gas flow rates, this process is less expensive than incineration.

An externally-fired rotary dryer is used to volatilize the water and organic contaminants into an inert carrier gas stream. The processed solids are then cooled with condensed water.

The moisture content is adjusted to eliminate dusting and produce a solid that is ready to be placed and compacted in its original location. The feed rate, the dryer temperature, and the residence time of materials in the dryer can be adjusted to control the degree of contaminant removal.

The organic contaminants and water vapor driven from the solid are transported out of the dryer by an inert nitrogen carrier gas. The carrier gas flows through a duct to the gas treatment system, where organic vapors, water vapors, and dust particles are removed and recovered from the gas. The gas first passes through a high-energy scrubber. Dust particles and 10 to 30 percent of the organic contaminants are removed by the scrubber. The gas then passes through two heat exchangers in series, where it is cooled to less than 40°F. Most of the remaining organic and water vapors are condensed as liquids in the heat exchangers.

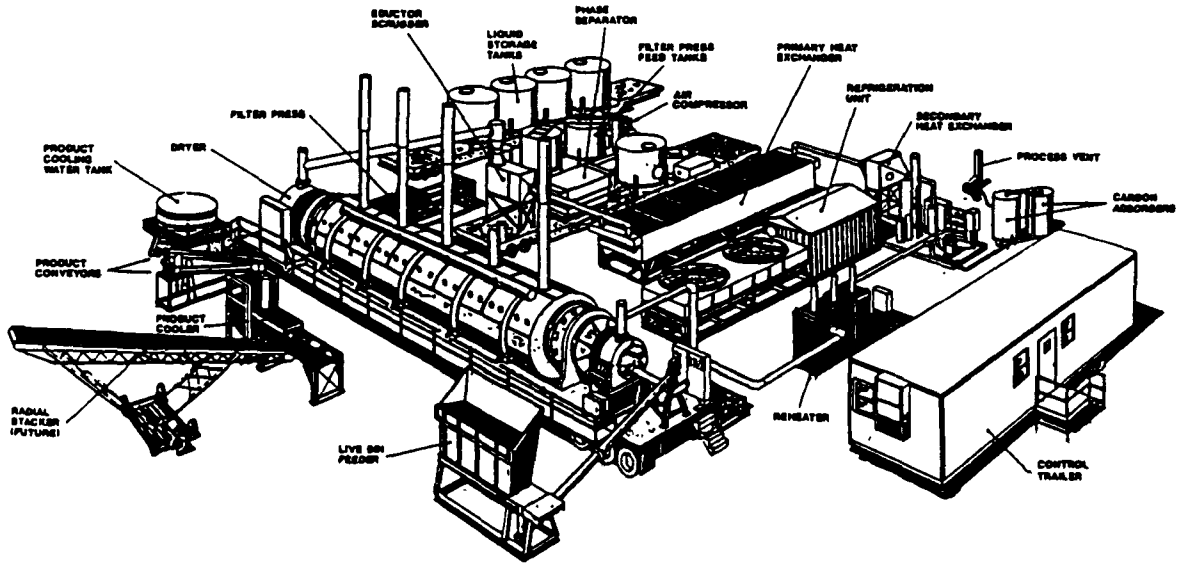


Figure 1 Pilot-Scale X*TRAX System

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles EPA/540/5-90/006 (1990).

The majority of the carrier gas passing through the gas treatment system is reheated and recycled to the dryer. Approximately 5 to 10 percent of the gas is cleaned by passing it through a filter and two carbon adsorbers, before it is discharged to the atmosphere. The volume of gas released from this process vent is approximately 100 to 200 times less than an equivalent capacity incinerator. This discharge helps maintain a small negative pressure within the system and prevents potentially contaminated gases from leaking. The discharge also allows makeup nitrogen to be added to the system, preventing oxygen concentrations from exceeding combustibility limits.

WASTE APPLICABILITY:

This technology was developed primarily for on-site remediation of organic contaminated soils. The process can remove and collect volatiles, semivolatiles, and PCBs, and has been demonstrated on a variety of soils ranging from sand to very cohesive clays. Filter cakes and pond sludges have also been successfully processed. In most cases, volatile organics are reduced to below 1 ppm and frequently to below the laboratory detection level. Semivolatile organics are typically reduced to less than 10 ppm and frequently below 1 ppm. Soils containing 120 to 6,000 ppm PCBs have been reduced to 2 to 25 ppm.

The process is not applicable to heavy metals, with the exception of mercury. However, stabilization agents can be added to the feed or treated solids before cooling for metals treatment. Tars and heavy pitches create material handling problems.

STATUS:

CWM currently has three X*TRAX systems available: laboratory, pilot, and full-scale. There are two laboratory-scale systems being used for treatability studies. One system is operated by Chem Nuclear systems, Inc. in Barnwell, SC for mixed (RCRA/Radioactive) wastes; and the other by CWM RD&D at its facility in Geneva, IL, for RCRA and TSCA wastes. More than 30 tests have been completed since January 1988. Results from these laboratory-scale tests included 97.9 percent removal efficiency for soil contaminated with 805 ppm PCBs.

The pilot-scale system is in operation at the CWM Kettleman Hills facility in California. During 1989-90, ten different PCB-contaminated soils were processed under a TSCA RD&D permit which expired in January 1990. For soils containing 120 to 6,000 ppm PCBs, the removal efficiency ranged from 97.2 to 99.5%. Nine of the ten soils were reduced to less than 25 ppm.

The first Model 200 full-scale X*TRAX system was completed in early 1990 and is shown in Figure 1. The system will be used to remediate 35,000 tons of PCB-contaminated soil. EPA plans to conduct a SITE demonstration during this remediation.

FOR FURTHER INFORMATION:

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Technology Developer Contact:
Carl Swanstrom
Chemical Waste Management, Inc.
Geneva Research Center
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Geneva, IL 60134
708-513-4578

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles EPA/540/5-90/006 (1990).

SITE Technology Profile

DEMONSTRATION PROGRAM

RECYCLING SCIENCES INTERNATIONAL, INC.
[formerly American Toxic Disposal]
(Desorption and Vapor Extraction System)

TECHNOLOGY DESCRIPTION:

The Desorption and Vapor Extraction System (DAVES) uses a low-temperature, fluidized bed to remove organic and volatile inorganic compounds from soils, sediments, and sludges. Contaminated materials are fed into a co-current, fluidized bed, where they are well mixed with hot air (about 1,000 to 1,400° F) from a gas-fired heater (Figure 1). Direct contact between the waste material and the hot air forces water and contaminants from the waste into the gas stream at a relatively low fluidized-bed temperature (about 320 ° F). The heated air, vaporized water and organics, and entrained particles flow out of the dryer to a gas treatment system.

The gas treatment system removes solid particles, vaporized water, and organic vapors from the air stream. A cyclone separator and baghouse remove most of the particulates in the gas stream from the dryer. Vapors from the cyclone separator are cooled in a venturi scrubber, counter-current washer, and chiller section before they are treated in a vapor-phase carbon adsorption system. The liquid residues from the system are centrifuged, filtered, and passed through two activated carbon beds arranged in series.

By-products from the DAVES treatment include: (1) approximately 96 to 98 percent of solid waste feed as clean, dry solid; (2) a small quantity of centrifuge sludge containing organics; (3) a small quantity of spent adsorbent carbon; (4) wastewater that may need further treatment; and (5) small quantities of baghouse and cyclone dust.

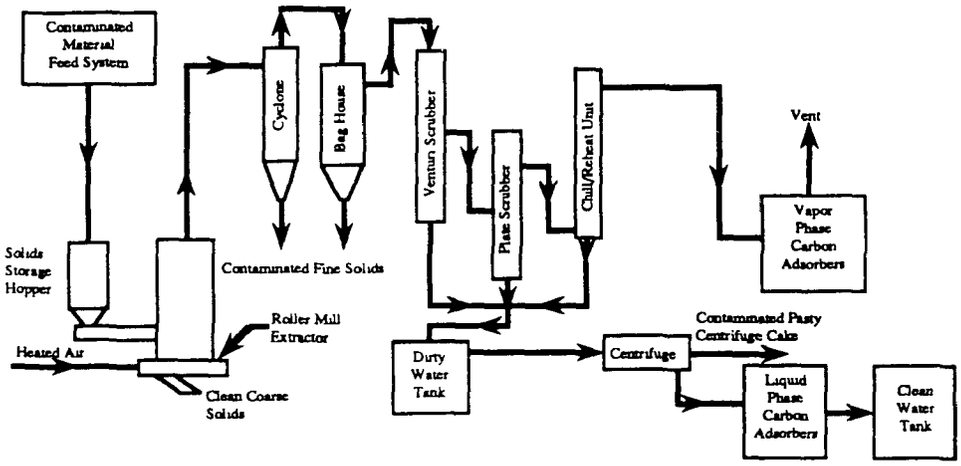

Figure 1. Process flow diagram.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

This technology can remove volatile and semivolatile organics, including polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), and pentachlorophenol (PCP), volatile inorganics (tetraethyl lead), and some pesticides from soil, sludge, and sediment, In general, the process treats waste containing less than 5 percent total organic contaminants and 30 to 90 percent solids. Nonvolatile inorganic contaminants (such as metals) in the waste feed do not inhibit the process but are not treated.

STATUS:

EPA is currently selecting a demonstration site for this process. The wastes preferred for the demonstration are harbor or river sediments containing at least 50 percent solids and contaminated with PCBs and other volatile or semivolatile organics. Soil with these characteristics may also be acceptable. About 300 tons of waste are needed for a two-week test. The demonstration may potentially be held at the selected demonstration site or wastes may be transported to a facility in Arizona that is owned by the developer. Major test objectives are to evaluate feed handling, decontamination of solids, and treatment of gases generated by the process.

FOR FURTHER INFORMATION:

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United States Environmental Protection Agency	Office of Emergency and Remedial Response Washington, DC 20460	Office of Research and Development Cincinnati, OH 45268
Superfund	EPA/540/2-91/008	May 1991

EPA

Engineering Bulletin
Thermal Desorption Treatment

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants and contaminants as a principal element." The Engineering Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial investigation scoping needs. Addenda will be issued periodically to update the original bulletins.

Abstract

Thermal desorption is an ex situ means to physically separate volatile and some semivolatile contaminants from soil, sediments, sludges, and filter cakes. For wastes containing up to 10% organics or less, thermal desorption can be used alone for site remediation. It also may find applications in conjunction with other technologies or be appropriate to specific operable units at a site.

Site-specific treatability studies may be necessary to document the applicability and performance of a thermal desorption system. The EPA contact indicated at the end of this bulletin can assist in the definition of other contacts and sources of information necessary for such treatability studies.

Thermal desorption is applicable to organic wastes and generally is not used for treating metals and other inorganics Depending on the specific thermal desorption vendor selected, the technology heats contaminated media between 200-1000°F, driving off water and volatile contaminants. Offgases may be burned in an afterburner, condensed to reduce the volume to be disposed, or captured by carbon adsorption beds.

Commercial-scale units exist and are in operation. Thermal desorption has been selected at approximately fourteen Superfund sites [1]* [2]. Three Superfund Innovative Technology Evaluation demonstrations are planned for the next year.

The final determination of the lowest cost alternative will be more site-specific than process equipment dominated. This bulletin provides information on the technology applicability, limitations, the types of residuals produced, the latest performance data, site requirements, the status of the technology, and sources for further information.

Technology Applicability

Thermal desorption has been proven effective in treating contaminated soils, sludges, and various filter cakes. Chemical contaminants for which bench-scale through full-scale treatment data exist include primarily volatile organic compounds (VOCs), semivolatiles, and even higher boiling point compounds, such as polychlorinated biphenyls (PCBs) [3][4][5][6]. The technology is not effective in separating inorganics from the contaminated medium. Volatile metals, however, may be removed by higher temperature thermal desorption systems.

Some metals may be volatilized by the thermal desorption process as the contaminated medium is heated. The presence of chlorine in the waste can also significantly affect the volatilization of some metals, such as lead. Normally the temperature of the medium achieved by the process does not oxidize the metals present in the contaminated medium [7, p. 85].

The process is applicable for the separation of organics from refinery wastes, coal tar wastes, wood-treating wastes, creosote-contaminated soils, hydrocarbon-contaminated soils, mixed (radioactive and hazardous) wastes, synthetic rubber processing wastes, and paint wastes [8, p. 2][4][9].

Performance data presented in this bulletin should not be considered directly applicable to other Superfund sites. A number of variables, such as the specific mix and distribution

* [reference number, page number]

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Table 1
RCRA Codes for Wastes Treated by Thermal Desorption

Wood Treating Wastes	K001
Dissolved Air Flotation (DAF) Float	K048
Slop Oil Emulsion Solids	K049
Heat Exchanger Bundles Cleaning Sludge	K050
American Petroleum Institute (API) Separator Sludge	K051
Tank Bottoms (leaded)	K052

Table 2
Effectiveness of Thermal Desorption on General Contaminant Groups for Soil, Sludge, Sediments, and Filter Cakes

		Effectiveness			
	Contaminant Groups	*Soil*	*Sludge*	*Sedi-ments*	*Filter Cakes*
Organic	Halogenated volatiles	■	▼	▼	■
	Halogenated semivolatiles	■	▼	▼	■
	Nonhalogenated volatiles	■	▼	▼	■
	Nonhalogenated semivolatiles	■	▼	▼	■
	PCBs	■	▼	▼	▼
	Pesticides	■	▼	▼	▼
	Dioxins/Furans	■	▼	▼	▼
	Organic cyanides	▼	▼	▼	▼
	Organic corrosives	❑	❑	❑	❑
Inorganic	Volatile metals	■	▼	▼	▼
	Nonvolatile metals	❑	❑	❑	❑
	Asbestos	❑	❑	❑	❑
	Radioactive materials	❑	❑	❑	❑
	Inorganic corrosives	❑	❑	❑	❑
	Inorganic cyanides	❑	❑	❑	❑
Reactive	Oxidizers	❑	❑	❑	❑
	Reducers	❑	❑	❑	❑

■ Demonstrated Effectiveness. Successful treatability test at some scale completed

▼ Potential Effectiveness. Expert opinion that technology will work

❑ No Expected Effectiveness. Expert opinion that technology will not work

of contaminants, affect system performance. A thorough characterization of the site and a well-designed and conducted treatability study are highly recommended.

Table 1 lists the codes for the specific Resource Conservation and Recovery Act (RCRA) wastes that have been treated by this technology [8, p. 2][4][9]. The indicated codes were derived from vendor data where the objective was to determine thermal desorption effectiveness for these specific industrial wastes. The effectiveness of thermal desorption on general contaminant groups for various matrices is shown in Table 2. Examples of constituents within contaminant groups are provided in "Technology Screening Guide For Treatment of CERCLA Soils and Sludges" [7, p. 10]. This table is based on the current available information or professional judgment where no information was available. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the treatment efficiencies achieved will be acceptable at other sites. For the ratings used for this table, demonstrated effectiveness means that, at some scale, treatability was tested to show the technology was effective for that particular contaminant and medium. The ratings of potential effectiveness or no expected effectiveness are both based upon expert judgment. Where potential effectiveness is indicated, the technology is believed capable of successfully treating the contaminant group in a particular medium. When the technology is not applicable or will probably not work for a particular combination of contaminant group and medium, a no expected effectiveness rating is given. Another source of general observations and average removal efficiencies for different treatability groups is contained in the Superfund Land Disposal Restrictions (LDR) Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions," (OSWER Directive 9347.3-06FS, September 1990) [10] and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions," (OSWER Directive 9347.3-06BFS, September 1990) [11].

Limitations

The primary technical factor affecting thermal desorption performance is the maximum bed temperature achieved. Since the basis of the process is physical removal from the medium by volatilization, bed temperature directly determines which organics will be removed.

The contaminated medium must contain at least 20 percent solids to facilitate placement of the waste material into the desorption equipment [3, p. 9]. Some systems specify a minimum of 30 percent solids [12, p. 6].

As the medium is heated and passes through the kiln or desorber, energy is lost in heating moisture contained in the contaminated soil. A very high moisture content can result in low contaminant volatilization or a need to recycle the soil through the desorber. High moisture content, therefore, causes increased treatment costs.

Material handling of soils that are tightly aggregated or largely clay, or that contain rock fragments or particles greater than 1-1.5 inches can result in poor processing performance due to caking. Also, if a high fraction of fine silt or clay exists in the matrix, fugitive dusts will be generated [7, p. 83] and a greater dust loading will be placed on the downstream air pollution control equipment [12, p. 6].

The treated medium will typically contain less than 1 percent moisture. Dust can easily form in the transfer of the treated medium from the desorption unit, but can be mitigated by water sprays. Normally, clean water from air pollution control devices can be used for this purpose.

Although volatile organics are the primary target of the thermal desorption technology, the total organic loading is limited by some systems to up to 10 percent or less [13, p. II-

30]. As in most systems that use a reactor or other equipment to process wastes, a medium exhibiting a very high pH (greater than 11) or very low pH (less than 5) may corrode the system components [7, p. 85].

There is evidence with some system configurations that polymers may foul and/or plug heat transfer surfaces [3, p. 9]. Laboratory/field tests of thermal desorption systems have documented the deposition of insoluble brown tars (presumably phenolic tars) on internal system components [14, p. 76].

High concentrations of inorganic constituents and/or metals will likely not be effectively treated by thermal desorption. The maximum bed temperature and the presence of chlorine can result in volatilization of some inorganic constituents in the waste, however.

Technology Description

Thermal desorption is any of a number of processes that use either indirect or direct heat exchange to vaporize organic contaminants from soil or sludge. Air, combustion gas, or inert gas is used as the transfer medium for the vaporized components. Thermal desorption systems are physical separation processes and are not designed to provide high levels of organic destruction, although the higher temperatures of some systems will result in localized oxidation and/or pyrolysis. Thermal desorption is not incineration, since the destruction of organic contaminants is not the desired result. The bed temperatures achieved and residence times designed into thermal desorption systems will volatilize selected contaminants, but typically not oxidize or destroy them. System performance is typically measured by comparison of untreated soil/sludge contaminant levels with those of the processed soil/sludge. Soil/sludge is typically heated to 200 - 1000° F, based on the thermal desorption system selected.

Figure 1 is a general schematic of the thermal desorption process.

Waste material handling (1) requires excavation of the contaminated soil or sludge or delivery of filter cake to the system. Typically, large objects greater than 1.5 inches are screened from the medium and rejected. The medium is then delivered by gravity to the desorber inlet or conveyed by augers to a feed hopper [8, p. 1].

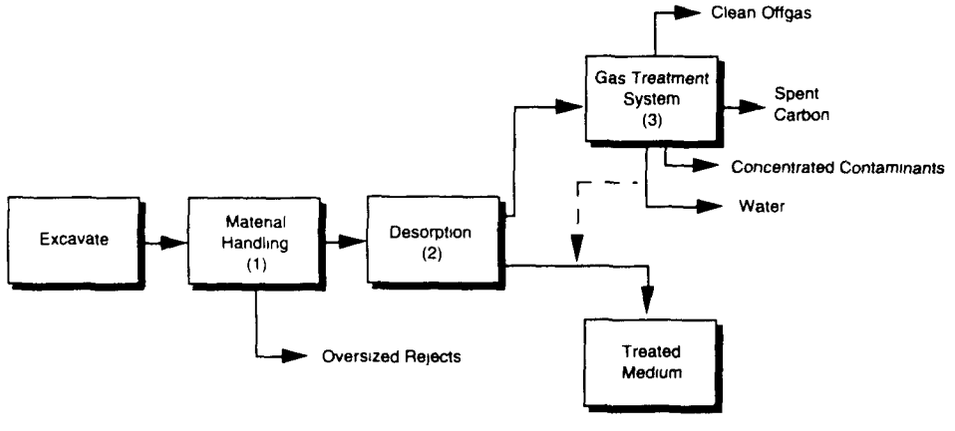
Significant system variation exists in the desorption step (2). The dryer can be an indirectly fired rotary asphalt kiln, a single (or set of) internally heated screw auger(s), or a series of externally heated distillation chambers. The latter process uses annular augers to move the medium from one volatilization zone to the next. Additionally, testing and demonstration data exist for a fluidized-bed desorption system [12].

The waste is intimately contacted with a heat transfer surface, and highly volatile components (including water) are driven off. An inert gas, such as nitrogen, may be injected in a countercurrent sweep stream to prevent contaminant combustion and to vaporize and remove the contaminants [8, p. 1][4]. Other systems simply direct the hot gas stream from the desorption unit [3, p. 5][5].

The actual bed temperature and residence time are the primary factors affecting performance in thermal desorption. These parameters are controlled in the desorption unit by using a series of increasing temperature zones [8, p. 1], multiple passes of the medium through the desorber where the operating temperature is sequentially increased, separate compartments where the heat transfer fluid temperature is higher, or sequential processing into higher temperature zones [15][16]. Heat transfer fluids used to date include hot combustion gases, hot oil, steam, and molten salts.

Offgas from desorption is typically processed (3) to remove particulates. Volatiles in the offgas may be burned in an afterburner, collected on activated carbon, or recovered in condensation equipment. The selection of the gas treatment system will depend on the concentrations of the contaminants, cleanup standards, and the economics of the offgas treatment system(s) employed.

Figure 1
Schematic Diagram of Thermal Desorption



Process Residuals

Operation of thermal desorption systems typically creates up to six process residual streams: treated medium, oversized medium rejects, condensed contaminants and water, particulate control system dust, clean offgas, and spent carbon (if used). Treated medium, debris, and oversized rejects may be suitable for return onsite.

Condensed water may be used as a dust suppressant for the treated medium. Scrubber purge water can be purified and returned to the site wastewater treatment facility (if available), disposed to the sewer [3, p. 8] [8, p. 2] [4, p. 2], or used for rehumidification and cooling of the hot, dusty media. Concentrated, condensed organic contaminants are containerized for further treatment or recovery.

Dust collected from particulate control devices may be combined with the treated medium or, depending on analyses for carryover contamination, recycled through the desorption unit.

Clean offgas is released to the atmosphere. If used, spent carbon may be recycled by the original supplier or other such processor.

Site Requirements

Thermal desorption systems are transported typically on specifically adapted flatbed semitrailers. Since most systems consist of three components (desorber, particulate control, and gas treatment), space requirements on site are typically less than 50 feet by 150 feet, exclusive of materials handling and decontamination areas.

Standard 440V, three-phase electrical service is needed. Water must be available at the site The quantity of water needed is vendor and site specific.

Treatment of contaminated soils or other waste materials require that a site safety plan be developed to provide for personnel protection and special handling measures. Storage should be provided to hold the process product streams until they have been tested to determine their acceptability for disposal or release. Depending upon the site, a method to store waste that has been prepared for treatment may be necessary. Storage capacity will depend on waste volume.

Onsite analytical equipment capable of determining site-specific organic compounds for performance assessment make the operation more efficient and provide better information for process control.

Performance Data

Several thermal desorption vendors report performance data for their respective systems ranging from laboratory treatability studies to full-scale operation at designated Superfund sites [17][9][18]. The quality of this information has not been determined. These data are included as a general guideline to the performance of thermal desorption equipment, and may not be directly transferrable to a specific Superfund site. Good site characterization and treatability studies are essential in further refining and screening the thermal desorption technology.

Chem Waste Management's (CWM's) X*TRAX™ System has been tested at laboratory and pilot scale. Pilot tests were performed at CWM's Kettleman Hills facility in California. Twenty tons of PCB- and organic-contaminated soils were processed through the 5 TPD pilot system. Tables 3 and 4 present the results of PCB separation from soil and total hydrocarbon emissions from the system, respectively [4].

During a non-Superfund project for the Department of Defense, thermal desorption was used in a full-scale demonstration at the Tinker Air Force Base in Oklahoma. The success of this project led to the patenting of the process by Weston Services, Inc. Since then, Weston has applied its low-temperature thermal treatment (LT^3) system to various contaminated soils at bench-scale through full-scale projects [19]. Table 5 presents a synopsis of system and performance data for a full-scale treatment of soil contaminated with No. 2 fuel oil and gasoline at a site in Illinois.

Canonie Environmental has extensive performance data for its Low Temperature Thermal Aeration ($LTTA^{SM}$) system at full-scale operation (15-20 cu. yds. per hour). The $LTTA^{SM}$ has been applied at the McKin (Maine), Ottati and Goss (New Hampshire) and Cannon Engineering Corp. (Massachusetts) Superfund sites Additionally, the $LTTA^{SM}$ has been used at the privately-funded site in South Kearney (New Jersey). Table

Table 3
PCB Contaminated Soils
Pilot X*TRAX™ [4]

Matrix	*Feed (ppm)*	*Product (ppm)*	*Removal (%)*
Clay	5,000	24	99.3
Silty Clay	2,800	19	99 5
Clay	1,600	4 8	99.7
Sandy	1,480	8.7	99.1
Clay	630	17	97.3

Table 4
Pilot X*TRAX™
TSCA Testing - Vent Emissions [4]

Total Hydrocarbons (ppm-V)				
Before Carbon	*After Carbon*	*Removal (%)*	*VOC (lbs/day)*	*PCB* (mg/m^3)*
1,320	57	95.6	0.02	<0.00056
1,031	72	93.0	0.03	<0.00055
530	35	93.3	0.01	<0.00051
2,950	170	94.2	0.07	<0.00058
2,100	180	91 4	0 08	<0.00052

*Note: OSHA permits 0.50 mg/m^3 PCB (1254) for 8-hr exposure.

6 presents a summary of Canonie LTTA℠ data [5]. The Cannon Engineering (Mass) site, which was not included in Table 6, successfully treated a total of 11,330 tons of soil, containing approximately 1803 lbs. of VOC [20].

T.D.I. Services, Inc. has demonstrated its HT-5 Thermal Distillation Process at pilot- and full-scale for a variety of RCRA-listed and other wastes that were prepared to simulate American Petroleum Institute (API) refinery sludge [8]. The company has conducted pilot- and full-scale testing with the API sludge to demonstrate the system's ability to meet Land Ban Disposal requirements for K048 through K052 wastes. Independent evaluation by Law Environmental confirms that the requirements were met, except for TCLP levels of nickel, which were blamed on a need to "wear-in" the HT-5 system [21, p. ii].

Remediation Technologies, Inc. (ReTec) has performed numerous tests on RCRA-listed petroleum refinery wastes. Table 7 presents results from treatment of refinery vacuum

Table 5
Full-Scale Performance Results for the LT³ System [19]

Contaminant	Soil Range (ppb)	Treated Range (ppb)	Range of Removal Efficiency
Benzene	1000	5.2	99.5
Toluene	24000	5.2	99.9
Xylene	110000	<1.0	>99.9
Ethyl benzene	20000	4.8	99.9
Napthalene	4900	<330	>99.3
Carcinogenic			
Priority PNAs	<6000	<330–590	<90.2–94.5
Non-carcinogenic			
Priority PNAs	890–6000	<330–450	<62.9–94.5

Table 6
Summary Results of the LTTA℠ Full-Scale Cleanup Tests [5]

Site	Processed	Contaminant	Soil (ppm)	Treated (ppm)
S. Kearney	16000 tons	VOCs PAHs	177.0 (avg.) 35.31 (avg.)	0.87 (avg.) 10.1 (avg.)
McKin	>9500 cu yds 2000 cu yds	VOCs PAHs	ND-3310	ND-0.04 <10
Ottati & Goss	4500 cu yds	VOCs	1500 (avg.)	<0.2 (avg.)

Table 7
ReTec Treatment Results-Refinery Vacuum Filter Cake (A) [3]

Compound	Original Sample (ppm)	Treated Sample (ppm)	Removal Efficiency (%)
Naphthalene	<0.1	<0.1	---
Acenaphthylene	<0.1	<0.1	---
Acenaphthene	<0.1	<0.1	---
Fluorene	10.49	<0.1	>98.9
Phenanthrene	46.50	<0.1	>99.3
Anthracene	9.80	<0.1	>96.6
Fluoranthrene	73.94	<0.1	>99.8
Pyrene	158.37	<0.1	>99.9
Benzo(b)anthracene	56.33	1.43	97.5
Chrysene	64.71	<0.1	>99.9
Benzo(b)fluoranthene	105.06	2.17	97.9
Benzo(k)fluoranthene	225.37	3.64	98.4
Benzo(a)pyrene	174.58	1.89	98.9
Dibenz(ab)antracene	477.44	10.25	97.8
Benzo(ghi)perylene	163.53	5.09	96.6
Indeno(123-cd)pyrene	122.27	4.16	96.6
Treatment Temperature: 450°F			

Table 8
ReTec Treatment Results-Creosote Contaminated Clay [3]

Compound	Original Sample (ppm)	Treated Sample (ppm)	Removal Efficiency (%)
Naphthalene	1321	<0.1	>99.9
Acenaphthylene	<0.1	<0.1	---
Acenaphthene	293	<0.1	>99.96
Fluorene	297	<0.1	>99.96
Phenanthrene	409	1.6	99.6
Anthracene	113	<0.1	>99.7
Fluoranthrene	553	1.5	99.7
Pyrene	495	2.0	99.6
Benzo(b)anthracene	59	<0.1	>99.99
Chrysene	46	<0.1	>99.8
Benzo(b)fluoranthene	14	2.5	82.3
Benzo(k)fluoranthene	14	<0.1	>99.8
Benzo(a)pyrene	15	<0.1	>99.9
Dibenzo(ab)anthracene	<0.1	<0.1	---
Benzo(ghi)perylene	7	<0.1	>99.4
Indeno(123-cd)pyrene	3	<0.1	>99.3
Treatment Temperature: 500°F			

Table 9
ReTec Treatment Results-Coal Tar Contaminated Soils [3]

Compound	Original Sample (ppm)	Treated Sample (ppm)	Removal Efficiency (%)
Benzene	1.7	<0.1	>94
Toluene	2.3	<0.1	>95
Ethylbenzene	1.6	<0.1	>93
Xylenes	6.3	<0.3	>95
Naphthalene	367	<1.7	>99
Fluorene	114	<0.2	>99
Phenanthrene	223	18	91.9
Anthracene	112	7.0	93.8
Fluoranthrene	214	15	93.0
Pyrene	110	11	90.0
Benzo(b)anthracene	56	<1.4	>97
Chrysene	58	3.7	93.6
Benzo(b)fluoranthene	45	<1.4	>97
Benzo(k)fluoranthene	35	<2.1	>94
Benzo(a)pyrene	47	<0.9	>98
Benzo(ghi)perylene	24	<1.1	>95
Indeno(123-cd)pyrene	27	<6.2	>77
Treatment Temperature: 450°F			

filter cake. Tests with creosote-contaminated clay and coal tar-contaminated soils showed significant removal efficiencies (Tables 8 and 9). All data were obtained through use of ReTec's 100 lb/h pilot scale unit processing actual industrial process wastes [3].

Recycling Sciences International, Inc. (formerly American Toxic Disposal, Inc.) has tested its Desorption and Vaporization Extraction System (DAVES), formerly called the Vaporization Extraction System (VES), at Waukegan Harbor, Illinois. The pilot-scale test demonstrated PCB removal from material containing up to 250 parts per million (ppm) to levels less than 2 ppm [12].

RCRA LDRs that require treatment of wastes to best demonstrated available technology (BDAT) levels prior to land disposal may sometimes be determined to be applicable or relevant and appropriate requirements for CERCLA response actions. Thermal desorption can produce a treated waste that meets treatment levels set by BDAT but may not reach these treatment levels in all cases. The ability to meet required treatment levels is dependent upon the specific waste constituents and the waste matrix. In cases where thermal desorption does not meet these levels, it still may, in certain situations, be selected for use at the site if a treatability variance establishing alternative treatment levels is obtained. Treatability variances are justified for handling complex soil and debris matrices. The following guides describe when and how to seek a treatability variance for soil and debris: Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions" (OSWER Directive 9347.3-06FS, September 1990) [10], and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-06BFS, September 1990) [11]. Another approach could be to use other treatment techniques in series with thermal desorption to obtain desired treatment levels.

Technology Status

Significant theoretical research is ongoing [22][23], as well as direct demonstration of thermal desorption through both treatability testing and full-scale cleanups.

A successful pilot-scale demonstration of Japanese soils "roasting" was conducted in 1980 for the recovery of mercury from highly contaminated (up to 15.6 percent) soils at a plant site in Tokyo. The high concentration of mercury made recovery and refinement to commercial grade (less than 99.99 percent purity) economically feasible [24].

In this country, thermal desorption technologies are the selected remedies for one or more operable units at fourteen Superfund sites. Table 10 lists each site's location, primary contaminants, and present status [1][2].

Most of the hardware components of thermal desorption are available off the shelf and represent no significant problem of availability. The engineering and configuration of the systems are similarly refined, such that once a system is designed full-scale, little or no prototyping or redesign is required.

On-line availability of the full-scale systems described in this bulletin is not documented. However, since the ex situ system can be operated in batch mode, it is expected that component failure can be identified and spare components fitted quickly for minimal downtime.

Several vendors have documented processing costs per ton of feed processed. The overall range varies from $80 to $350 per ton processed [6][4, p. 12][5][3, p. 9]. Caution is recommended in using costs out of context because the base year of the estimates vary. Costs also are highly variable due to the quantity of waste to be processed, term of the remediation contract, moisture content, organic constituency of the contaminated medium, and cleanup standards to be achieved. Similarly, cost estimates should include such items as preparation of Work Plans, permitting, excavation, processing itself, QA/QC verification of treatment performance, and reporting of data.

EPA Contact

Technology-specific questions regarding thermal desorption may be directed to:

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FTS 340-6625 or (908) 321-6625

Table 10
Superfund Sites Specifying Thermal Desorption as the Remedial Action

Site	*Location*	*Primary Contaminants*	*Status*
Cannon Engineering (Bridgewater Site)	Bridgewater, MA (1)	VOCs (Benzene, TCE & Vinyl Chloride)	Project completed 10/90
McKin	McKin, ME (1)	VOCs (TCE, BTX)	Project completed 2/87
Ottati & Goss	New Hampshire (1)	VOCs (TCE; PCE; 1, 2-DCA, and Benzene)	Project completed 9/89
Wide Beach	Brandt, NY (2)	PCBs	In design • pilot study available 5/91
Metaltec/Aerosystems	Franklin Borough, NJ (2)	TCE and VOCs	In design • remedial design complete • remediation starting Fall '91
Caldwell Trucking	Fairfield, NJ (2)	VOCs (TCE, PCE, and TCA)	In design
Outboard Marine/ Waukegan Harbor	Waukegan Harbor, IL (5)	PCBs	In design • treatability studies complete
Reich Farms	Dover Township, NJ (02)	VOCs and Semivolatiles	Pre-design
Re-Solve	North Dartmouth, MA (1)	PCBs	In design • pilot study June/July '91
Waldick Aerospace Devices	New Jersey (2)	TCE and PCE	In design
Wamchem	Burton, SC (4)	BTX and SVOCs (Naphthalene)	In design • pilot study available 5/91
Fulton Terminals	Fulton, NY (2)	VOCs (Xylene, Styrene, TCE, Ethylbenzene, Toluene) and some PAHs	Pre-design
Stauffer Chemical	Cold Creek, AL (4)	VOCs and pesticides	Pre-design
Stauffer Chemical	Le Moyne, AL (4)	VOCs and pesticides	Pre-design

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Note: A more comprehensive bibliography is being developed.

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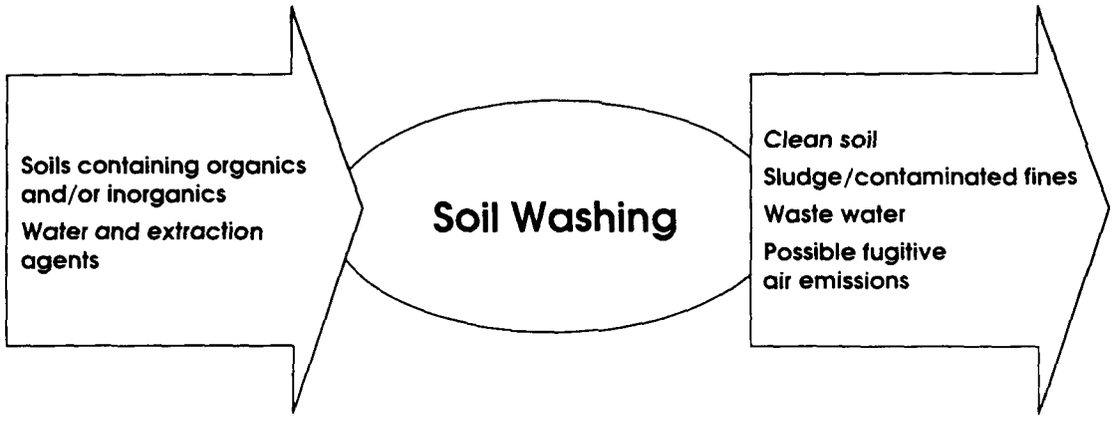
4.0 SOIL WASHING

4.1 TECHNOLOGY DESCRIPTION

Soil washing is an aqueous-based technology that, in general, uses mechanical processes to separate particles that contain contaminants. In this sense, it is a volume reduction or pretreatment technology. It makes use of the fact that contaminants have a tendency to adhere to the organic carbon and fine-grained soil fraction (i.e., silt and clay) as opposed to the coarse-grained mineral fraction (i.e., sand and gravel). In addition, or in some cases alternatively, contaminants may be removed from the soil as a result of being solubilized in the wash water. Surficial contamination is removed from the coarse fraction by abrasive scouring action. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent such as ethylene diamine tetra-acetic acid (EDTA) to help remove organics or heavy metals. Treated soil is cleaned of any residual additive compounds. The spent wash water is treated to remove the contaminants prior to recycling back to the treatment unit.



- Separation and volume reduction
- Residuals require subsequent treatment

4.2 TECHNOLOGY STATUS

- Through FY 90, soil washing has been selected as a remedial source control technology at 16 Superfund sites, including eight wood preserving sites (PAHs, PCP and metals), one lead battery recycling site, three pesticide sites, one site with VOCs and metals, and two with metals. It has been selected for one emergency response action.
- This technology is widely accepted in Europe, especially in Germany, the Netherlands, and Belgium.
- The Environmental Protection Agency (EPA) has designed and fabricated a Mobile Volume Reduction Unit (VRU) through the Risk Reduction Engineering Laboratory (RREL) in Edison, New Jersey. It has a capacity of 100 pounds of soil (dry basis) per hour and consists of process washing equipment and utility support services mounted on two heavy-duty semi-trailers. It will be available for treatability studies following a shake down and performance testing phase.

4.3 APPLICATIONS

- Soil washing may be used for a wide variety of organic, inorganic, and reactive contaminants.
- Because extraction additives are selective, the technology is more appropriate for non-complex wastes contaminated with either metals or organics.
- Because the technology is primarily a separation and volume reduction process, it is frequently used with other technologies. For example, soil washing may be used to separate the highly contaminated "fines" for further treatment. Because a much smaller volume needs treatment, the additional technology is more cost effective after the soil-washing step.
- Soil washing is very effective on sands and gravel. It is most cost effective when water alone (without additives) is sufficient to achieve cleanup levels.

4.4 TECHNOLOGY STRENGTHS

- Soil washing is favorably viewed by the public
- It is a relatively low cost alternative for separating wastes.
- The technology can utilize a closed treatment system that permits control of ambient volatile emissions.
- Testing to date indicates the technology can remove volatile organic contaminants with 90 to 99 percent effectiveness and semivolatile organics with 40 to 90 percent effectiveness.

4.5 TECHNOLOGY LIMITATIONS

- Effectiveness is highly dependent on site conditions. This process is relatively ineffective on soils with high silt and clay content.
- Washing additives (e.g., chelating agents, solvents, surfactants) may be tailored to site, soil, and contaminant conditions; however, these may be hazardous, difficult to recover, and interfere with wash water treatment.

4.6 POTENTIAL MATERIALS HANDLING REQUIREMENTS

- Excavation is required.
- The wastes may be screened to remove debris and large particles.
- Large particles may be reduced in size to achieve a feed size required by the equipment - less than 2 inches in diameter.
- The waste material, wash water, and any additives will require mixing to ensure adequate transfer of the contaminants.

4.7 WASTE CHARACTERISTICS AFFECTING PERFORMANCE

- Can be limited by complex waste mixtures.
- Can be limited by soils with high humic content and fine-grained clay particles.

4.8 EXHIBIT 1 - WASTE CHARACTERISTIC TABLE

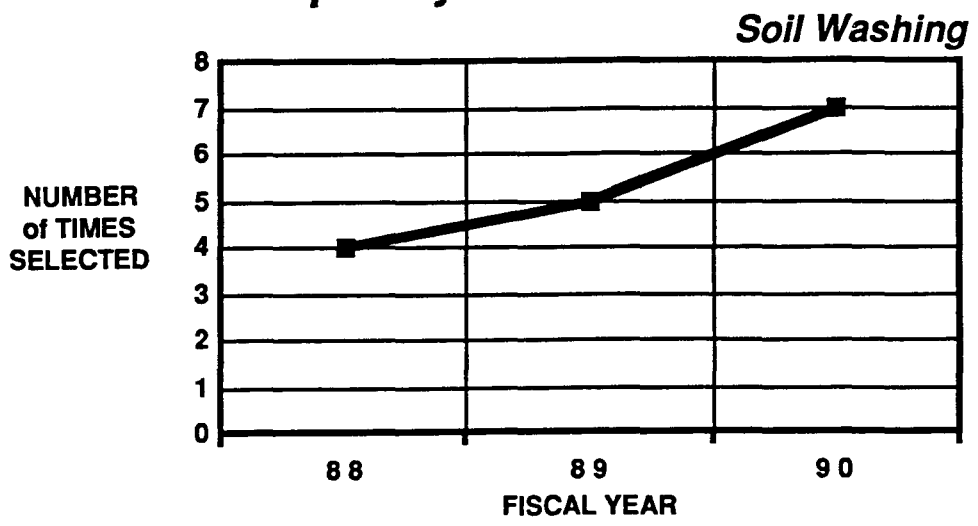
Waste Type: Soils
Technology: Soil Washing

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Unfavorable separation coefficient for contaminant	Excessive volumes of leaching medium required.	Equilibrium partition coefficient
Complex mixtures of waste types (e.g., metals with organics)	Formulation of suitable washing fluids difficult.	Analysis for priority pollutants, solubility data
Variation in waste composition	May require frequent reformulation of washing fluid.	Statistical sampling, analysis for priority pollutants
Unfavorable soil characteristics:		
• High humic content	Inhibition of desorption.	Analysis for organic matter
• Soil, solvent reactions	May reduce contaminant mobility.	Pilot testing
• Fine particle size (silt and clay)	Fine particles difficult to remove from washing fluid.	Soil particle size distribution, USGS soil classification
• Clay soil containing semivolatiles	Low recovery rate because organics are held more tenaciously.	
Unfavorable washing fluid characteristics:		
• Difficult recovery of solvent or surfactant	High cost if recovery low.	Bench-scale testing
• Poor treatability of washing fluid	Requires replacement of washing fluid.	Bench-scale testing, conventional analysis*
• Reduction of soil permeability	Surfactant adheres to soil to reduce effective porosity.	Permeability pilot testing
• High toxicity of washing fluid	Soil may require additional treatment for detoxification. Fluid processing requires caution.	Toxicity of washing fluid

* Conventional analysis should include organic content (e.g., BOD, COD, TOC), solids content, iron, manganese, and leachate pH.

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

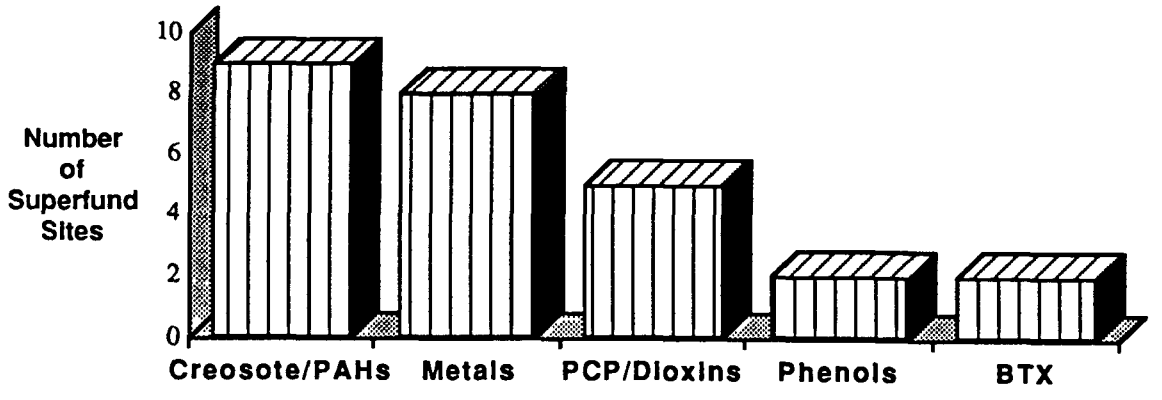
Selection Frequency*



* *Data derived from 1982 - 1990 Records of Decision (RODs) and anticipated design and construction activities.*

September 1991

Contaminants Treated By Soil Washing



* *Data derived from 1982 – 1990 Records of Decision (RODs) and anticipated design and construction activities. At some sites, the treatment is for more than one major contaminant.*

EXHIBIT 3 - INNOVATIVE TREATMENT TECHNOLOGIES - SEMI-ANNUAL STATUS REPORT

Soil Washing

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
2	Ewan Property, NJ* (09/29/89) Also see Solvent Extraction	Soil Washing (preceded by Solvent Extraction)	Industrial Waste Dumping	Soil (22,000 cy)	VOCs (BTX), SVOCs (Naphthalene and 2,4-dimethylphenol) and Metals (Chromium and Lead)	Predesign; Design completion planned Summer '94	PRP Lead	Craig DeBiase 212-264-5393 FTS 264-5393
2	GE Wiring Devices, PR (09/30/88)	Hydrometallurgical Treatment	Wiring Services Facility	Soil (5,500 cy)	Mercury	Predesign; Alternative being reconsidered	PRP Lead	Craig De Biase 212-264-5393 FTS 264-5393
2	King of Prussia, NJ (09/28/90)	Soil Washing	Recycling Facility	Soil, Sludges, Sediments (20,150 cy combined)	Metals (Chromium, Copper, and Silver)	Predesign; Design completion planned Summer '93	PRP Lead	Jim Hahnenberg 212-264-5387 FTS 264-5387
2	Myers Property, NJ (09/28/90) Also see Dechlorination	Soil Washing (preceded by Dechlorination)	Pesticide Manufacturing	Soil, Sediments (50,000 cy combined)	Metals (Aluminum, Cadmium, Chromium, Silver, and Sodium)	Predesign	Fund lead/In Negotiation	John Prince 212-264-1213 FTS 264-1213
2	Vineland Chemical, NJ (09/29/89) Also see In situ Flushing	Soil Washing	Pesticide Manufacturing	Sediments (62,600 cy)	Arsenic	Predesign	Fund Lead	Matthew Westgate 212-264-3406 FTS 264-3406
4	Cabot/Koppers, FL (09/27/90) Also see Bioremediation (In situ)	Soil Washing (may be followed by bioremediation of residual)	Wood Treating and Pine Tar Distillation Facility	Soil (6,400 cy)	SVOCs [Bis(2-ethylhexyl)phthalate, Dimethylphenol, Dinitrotoluene, Di-n-octyl-phthalate, Pentachlorophenol, and Penol], and PAHs	In design; pilot study planned; Design completion planned Spring '93	PRP Lead	Martha Barry 404-347-2643 FTS 257-2643
4	Cape Fear Wood Preserving, NC* (06/30/89)	Soil Washing	Wood Preserving	Soil (20,000 cy)	Creosote, PAHs, Copper, Chromium, Arsenic, and Benzene	In design; Design completion planned Fall '91; Bid advertisement scheduled for late Fall	Fund Lead	Jon Bornholm 404-347-7791 FTS 257-7791

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Soil Washing

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
4	American Creosote Works, FL* (09/28/89) Also see Bioremediation (Ex Situ)	Soil Washing (slurry-phase bioremediation for fines)	Wood Preserving	Soil (21,000 cy)	Creosote, PAHs, SVOCs (PCP), and Dioxins	In design; Design delayed for additional treatability testing	Fund Lead	Madelaine Streng 404-347-2643 FTS 257-2643
4	Coleman-Evans Wood Preserving, FL* (09/26/90) Also see Bioremediation (Ex situ)	Soil Washing (bioremediation of fines)	Wood Preserving	Soil (27,000 cy)	PCP, Dioxin	In design; Design completion planned Spring '92	Fund Lead	Tony Best 404-347-2643 FTS 257-2643
4	Southeastern Wood Preserving, MS (Emergency Response -AM signed 9/30/90) Also see Bioremediation (Ex situ)	Soil washing followed by slurry phase bioremediation	Wood preserving	Solids (8,000 cy)	SVOCs (PCP), PAHs, and creosote	Project ongoing; Demonstration on 700 cy 2/91 - 8/91; Full-scale cleanup began 8/91	Fund lead; OHM Remediation Services Corp.	Don Reiger 404-347-3931 FTS 257-7931
5	Moss American, WI (09/27/90) Also see Bioremediation (Ex situ)	Soil Washing (bioremediation of fines)	Wood Preserving	Soil (80,000 cy)	PAHs	Predesign; design completion planned 3/93	PRP Lead; Weston, Inc.	Betty Lavis 312-886-4784 FTS 886-4784
5	United Scrap Lead/SIA, OH* (09/30/88)	Soil Washing	Lead Battery Recycling	Soil (45,000 cy), Sediments (45,550 cy)	Lead and Arsenic	In design; Design completion planned Spring '93	Fund Lead	Anita Boseman 312-886-6941 FTS 886-6941
6	Arkwood, AR (09/28/90)	Soil Washing (incineration of residuals)	Wood Preserving	Soil (20,400 cy)	PCP, PNA, and Dioxins	Predesign	PRP Lead	Rick Erhart 214-655-6582 FTS 255-6582
6	Koppers/Texarkana, TX* (09/23/88)	Soil Washing	Wood Preserving	Soil (19,400 cy)	PAHs and SVOCs (PCP)	Predesign	PRP Lead	Ursula Lennox 214-655-6735 FTS 255-6735

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Soil Washing

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
6	South Cavalcade Street, TX (09/26/88) Also see In situ Flushing	Soil Washing	Wood Preserving & Coal Tar Distillation	Soil (19,500 cy)	PAHs	In design; Design completion planned Summer '93	PRP Lead	Mark Fite 214-655-6715 FTS 255-6715
8	Sand Creek Industrial (OU 5), CO* (09/28/90)	Soil Washing	Refinery, Pesticide Manufacturing, and Landfill	Soil (14,000 cy)	Chlordane, Dieldrin, 4,4-DDT, 2-4 D, Heptachlor, and Metals (Arsenic and Chromium)	In design; Design completion planned Spring '92	Fund Lead	Brian Pinkowski 303-293-1512 FTS 330-1512
9	Koppers (Oroville Plant), CA (09/13/89) Also see Bioremediation (In situ)	Soil Washing	Wood preserving	Soil, Sediments (200,000 cy combined)	PAHs, SVOCs (PCP), and Dioxin	In design; Design completion planned Summer '92	PRP Lead	Fred Schauffler 415-744-2365 FTS 484-2365

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

United States Environmental Protection Agency | Solid Waste And Emergency Response (OS-220) | Directive 9200.5-250FS November 1989

EPA

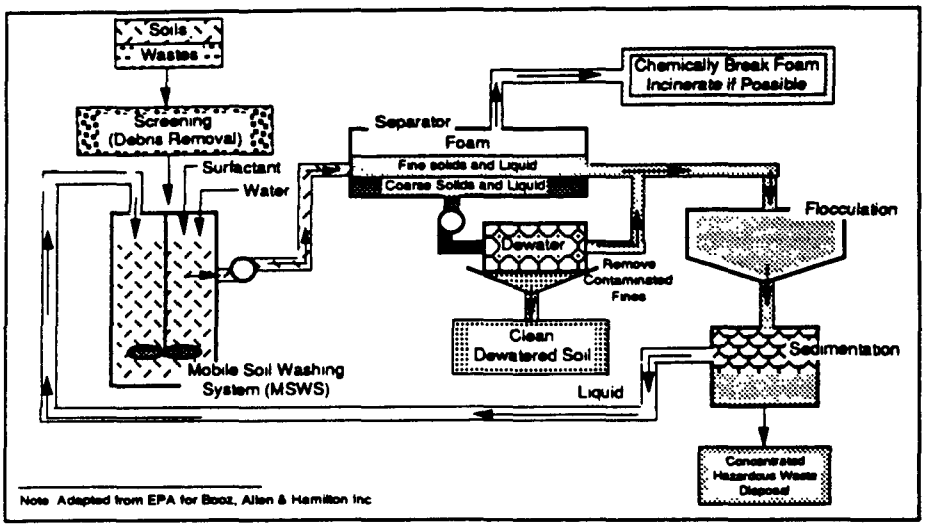
Innovative Technology

Soil Washing

TECHNOLOGY DESCRIPTION

Soil washing is potentially effective in treating various organic and inorganic waste groups. It was designed for the separation/segregation and volumetric reduction of hazardous materials in soils, sludges, and sediments. The process involves high energy contacting and mixing of excavated contaminated soils with an aqueous-based washing solution in a series of mobile washing units. A typical soil washing treatment flow diagram is shown in Figure 1.

Figure 1: Schematic Diagram of a Mobile Soil Washing Treatment Facility



Before treatment, the contaminated soil is passed through a coarse-mesh sieve to remove material greater than two inches (e.g., rocks, debris). The remaining material then enters a soil scrubbing unit, where it is sprayed with a washing fluid and subsequently rinsed. Contaminants are primarily concentrated in the fine-grained soil fraction (i.e., silt and clay) and are less tenaciously sorbed on the coarser-grained particles (i.e., sand). Accordingly, the sand fraction of the soil usually requires only the initial rinsing treatment to meet designated performance criteria prior to redeposition. The remaining silt/clay soil fraction enters a four-staged countercurrent contactor to further separate the contaminants from the solids. The treated solid fractions (less than 74 microns) are then rinsed, dewatered, and redeposited. The contaminated washing fluid, containing highly contaminated fine fractions (greater than 74 microns) is recycled through a conventional wastewater treatment system and is reintroduced into the treatment process. The fines are separated, removed, and dewatered and are handled/disposed as a manifested hazardous waste material.

Advantages of soil washing include a closed treatment system that permits control of ambient environmental conditions, potential significant volume reduction of the contaminant mass (depending on soil characteristics), wide application to varied waste groups, mobility of technology (hazardous wastes remain on-site), and relatively low cost compared to other multi-contaminant treatment technologies. Disadvantages include little reduction of the contaminant toxicity, and potentially hazardous chemicals (e.g., chelating washing solutions) may be brought on-site to be used in the process, and also may be difficult to remove from the treated soil fraction. Applications and limitations of soil washing are discussed in the following sections.

SITE CHARACTERISTICS AFFECTING TREATMENT FEASIBILITY

Soil washing has the potential to treat a wide variety of contaminants such as heavy metals, halogenated solvents, aromatics, gasoline and fuel oils, polychlorinated biphenyls (PCBs), and chlorinated phenols. The projected effectiveness of this treatment on general contaminant groups is provided in Table 1; treatability tests are required to determine the feasibility of soil washing for specific target contaminants at a particular site.

Factors limiting the effectiveness of soil washing include complex waste mixtures, high humic content in the soil, inhibiting solvent-soil reactions, and a high fine-grained clay particle fraction. Site-specific characteristics and their potential impact on the soil washing process are listed in Table 2.

Table 1
Effectiveness of Soil Washing Treatment on General Contaminant Groups for Soil and Debris

	Treatability Groups	Effectiveness
Organics	Halogenated volatiles	◒
	Halogenated semi-volatiles	◒
	Non-halogenated volatiles	◒
	Non-halogenated semi-volatiles	◒
	PCBs	◒
	Pesticides	◒
	Dioxins/Furans	◒
	Organic cyanides	◒
	Organic corrosives	◒
Inorganics	Volatile metals	◒
	Non-volatile metals	◒
	Asbestos	◒
	Radioactive materials	○
	Inorganic corrosives	◒
	Inorganic cyanides	◒
Reactive	Oxidizers	◒
	Reducers	◒

● Demonstrated Effectiveness ○ No Expected Effectiveness
◒ Potential Effectiveness X Potentially Detrimental

Table 2
Site-Specific Characteristics and Impacts on Soil Washing Treatment

Characteristics Impacting Process Feasibility	Reasons for Potential Impact	Actions to Minimize Impacts
Unfavorable separation coefficient for contamination	Excessive volumes of leaching medium required	Bench- and pilot-scale tests to determine a suitable washing solution
Complex mixtures of waste types (e.g., metals with organics)	Formulation of suitable washing fluids difficult	Employ secondary treatment technology
Unfavorable soil characteristics:		
• High humic content	Inhibition of desorption	Employ secondary treatment technology
• Soil, solvent reactions	May reduce contaminant mobility	Pilot testing to determine a suitable washing fluid
• Fine particle size (silt and clay)	Fine particles difficult to remove from washing fluid	None; or longer dewatering period
• Clay soil containing semi-volatiles	Low recovery rate because organics are held more tenaciously	None; or longer washing period
Unfavorable washing fluid characteristics:		
• Difficult recovery of solvent or surfactant	High cost if recovery low	Bench-scale testing to determine if technology is economically feasible
• Poor treatability of washing fluid	Requires replacement of washing fluid	Bench-scale testing to determine if technology is economically feasible
• High toxicity of washing fluid	Fluid processing requires caution, soil may require detoxification	Longer dewatering period, post-treatment of soils; bench- and pilot-scale tests to determine an alternate washing solution

TECHNOLOGY CONSIDERATIONS

Because soil washing is primarily a volume-reduction process that does not reduce the inherent toxicity of a contaminant, the major technology consideration is determining the initial composition and post-treatment of the washing fluid and contaminated fines. An ideal washing fluid should possess the following characteristics: a favorable separation coefficient for extraction, low volatility, low toxicity, safety and ease of handling, and efficient recoverability and treatability. Typical soil washing fluids may be composed of water only, or water in combination with organic solvents, chelating compounds, surfactants, acids, or bases; the exact washing fluid composition depends upon the chemistry of the target contaminant(s).

The treatment of the washing fluid is contingent upon the composition of the contaminants removed from the waste stream. For expensive washing fluids (e.g., lead chelating agents), the recyclability of the fluid is an important factor when determining the economic feasibility of the soil washing process. Full-scale soil washing units are projected to treat an average of 100 cubic yards of soil per day.

TECHNOLOGY STATUS

The following vendors claim to have successfully applied soil washing to various media and waste types and presently possess the technology to conduct pilot- and/or full-scale operation:

• MTA Remedial Resources, Inc., (MTARRI) uses technologies developed for mining and enhancing oil recovery to remove and concentrate organic contaminants from soils and sludges. In addition, MTA has treated various metallic compounds with acidic washing solutions. They state that 5 tons (5 percent) of contaminated treatment residue is generated per 100 tons of soil treated.

• BioTrol, Inc. employs soil washing as a pretreatment process in conjunction with biodegradation. EPA is presently evaluating the BioTrol Soil WashingTreatment System (BSTS) under the SITE program. BSTS will be demonstrated on wood-treating chemicals (i.e., PCP, PAHs, copper, chromium, and arsenic) at the MacGillis and Gibbs Site, New Brighton, Minnesota, by Fall 1989.

• EPA developed a mobile soil washing treatment system designed for water extraction of a broad range of hazardous materials from contaminated soils. The normal processing rate is 4 to 18 cubic yards of contaminated soil per hour depending on the average particle size. Treatability costs range from approximately $20,000 to over $100,000.

Vendor names, contacts, and addresses are listed in Table 3.

EPA has selected soil washing as a component of the source control remedy for five CERCLA sites. Site names, ROD sign dates, target contaminants, and waste volumes are provided in Table 4.

OFFICE OF RESEARCH AND DEVELOPMENT CONTACTS

Supplemental information concerning soil washing may be obtained from Richard P. Traver, P.E., U.S. EPA, Edison, New Jersey 08837, (201) 321-6677 or FTS 340-6677.

Table 3
Vendor Information

Company	Contact	Address
MTARRI	Paul Trost	1511 Washington Avenue Golden, CO 80401 (303) 279-4255
Ecova Corporation	Al Bourquin	3820 159th Avenue NE Redmond, WA 98052 (206) 883-1900
BioTrol, Inc.	Dale Pflug	11 Peavey Road Chaska, MN 55318 (612) 448-2515
U.S. EPA, Risk Reduction Engineering Laboratory	Richard P. Traver	Releases Control Branch Raritan Depot - Woodbridge Avenue Edison, NJ 08837-3679 (201) 321-6677
Soil Cleaning Company of America, Inc.	Verl Rothlisberger	753 Peralta Avenue San Leandro, CA 94577 (415) 568-1234

Table 4
Soil Washing Status at CERCLA Sites

SELECTED:		
Region 1 - Tinkham Garage, NH 9/86	TCE, PCE in Soil	10,800 cubic yards
Region 4 - Palmetto, SC 9/87	Arsenic, Chromium in Soil	19,850 cubic yards
Region 5 - United Scrap, OH 9/88	Arsenic, Lead in Soil	60,600 cubic yards
Region 6 - Koppers/Texarkana, TX 9/88	Arsenic in Soil	Not Provided
Region 6 - South Cavalcade, TX 9/88	PAHs in Soil	19,500 cubic yards

SITE Technology Profile

DEMONSTRATION PROGRAM

BIOTROL, INC.
(Soil Washing System)

TECHNOLOGY DESCRIPTION:

The Biotrol Soil Washing System is a patented, water-based, volume reduction process for treating excavated soil. Soil washing is applicable to contaminants concentrated in the fine size fraction of soil (silt, clay, and soil organic matter) and contaminants associated with the coarse soil fraction (sand and gravel), primarily surficial. The objective of the process is to concentrate the contaminants in a smaller volume of material separate from a washed soil product. The goal is that the soil product will meet appropriate cleanup standards.

After debris is removed, soil is mixed with water and subjected to various unit operations common to the mineral processing industry. Process steps can include mixing trommels, pug mills, vibrating screens, froth flotation cells, attrition scrubbing machines, hydrocyclones, screw classifiers, and various dewatering operations.

The core of the process is a multi-stage, counter-current, intensive scrubbing circuit with interstage classification. The scrubbing action disintegrates soil aggregates, freeing contaminated fine particles from the coarser sand and gravel. In addition, surficial contamination is removed from the coarse fraction by the abrasive scouring action of the particles themselves. Contaminants may also be solubilized as dictated by solubility characteristics or partition coefficients.

The efficiency of soil washing can be improved using surfactants, detergents, chelating agents, pH adjustment, or heat. In many cases, however, water alone is insufficient to achieve the desired level of contaminant removal while minimizing cost.

The volume of material requiring additional treatment or disposal is reduced significantly by separating the washed, coarser soil components from the process water and contaminated fine particles (Figure 1).

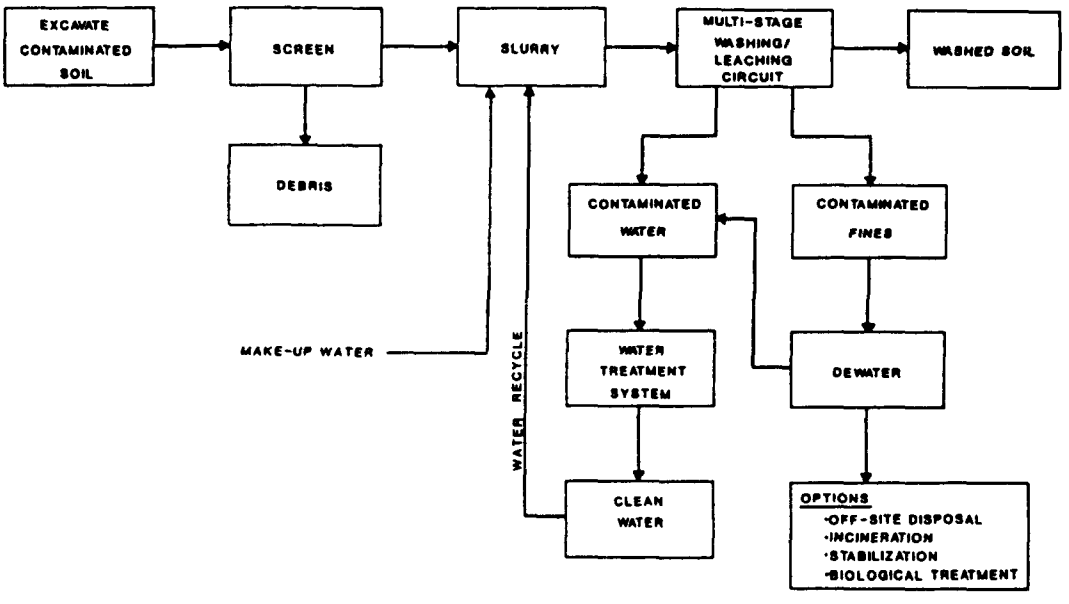


FIGURE 1. BIOTROL SOIL WASHING SYSTEM PROCESS FLOWSHEET.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles EPA/540/5-90/006 (1990).

The contaminated residual products can be treated by other methods. Process water is normally recycled after biological or physical treatment. Options for the contaminated fines can include off-site disposal, incineration, stabilization, or biological treatment.

WASTE APPLICABILITY:

This technology was initially developed to clean soils contaminated with wood preserving wastes such as polyaromatic hydrocarbons (PAHs) and pentachlorophenol (PCP). The technology is also applicable to soils contaminated with petroleum hydrocarbons, pesticides, polychlorinated biphenyls (PCBs), various industrial chemicals, and metals.

STATUS:

The SITE demonstration of the soil washing technology took place from September 25 to October 27, 1989 at the MacGillis & Gibbs Superfund site in New Brighton, Minnesota. A pilot-scale unit with a treatment capacity of 500 pounds per hour was operated 24 hours per day during the demonstration. Feed for the first phase of the demonstration (2 days) consisted of soil contaminated with 170 ppm PCP and 240 ppm total PAHS. During the second phase (7 days), soil containing 980 ppm PCP and 340 ppm total PAHs was fed to the system.

Contaminated process water from soil washing was treated biologically in a fixed film reactor and recycled. A portion of the contaminated fines generated during soil washing was treated biologically in a 3-stage, pilot-scale EIMCO Biolift™ reactor system supplied by the EIMCO Process Equipment Company.

Preliminary demonstration results showed that PCP levels in the washed soil were reduced by 91 to 93 percent. Biological treatment reduced PCP levels in the process water by 89 to 94 percent. Removal efficiencies increased as the test proceeded. Near the completion of the test, PCP removal was about 92 percent, while PAH removal ranged from 86 to 99 percent.

The demonstration reports are expected to be available in the first quarter 1991.

FOR FURTHER INFORMATION:

EPA Project Manager:
Mary K. Stinson
U.S. EPA
Risk Reduction Engineering Laboratory
Woodbridge Avenue
Edison, New Jersey 08837
908-321-6683
FTS: 340-6683

Technology Developer Contact:
John K. Sheldon
BioTrol, Inc.
11 Peavey Road
Chaska, Minnesota 55318
612-448-2515
Fax: 612-448-6050

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles EPA/540/5-90/006 (1990).

SITE Technology Profile

DEMONSTRATION PROGRAM

EXCALIBUR ENTERPRISES, INC.
(Soil Washing/Catalytic Ozone Oxidation)

TECHNOLOGY DESCRIPTION:

The Excalibur technology is designed to treat soils with organic and inorganic contaminants. The technology is a two-stage process: the first stage extracts the contaminants from the soil, and the second stage oxidizes contaminants present in the extract. The extraction is carried out using ultrapure water and ultrasound. Oxidation involves ozone, ultraviolet light, and ultrasound. The treatment products of this technology are decontaminated soil and inert salts.

A flow schematic of the system is shown in Figure 1. After excavation, contaminated soil is passed through a 1-inch screen. Soil particles retained on the screen are crushed using a hammermill and sent back to the screen. Soil particles passing through the screen are sent to a soil washer, where ultrapure water extracts the contaminants from the screened soil. Ultrasound acts as a catalyst to enhance soil washing. Typically, 10 volumes of water are added per volume of soil, generating a slurry of about 10-20 percent solids. This slurry is conveyed to a solid/liquid separator, such as a centrifuge or cyclone, to separate the decontaminated soil from the contaminated water. The decontaminated soil can be returned to its original location or disposed of appropriately.

After the solid/liquid separation, any oil present in the contaminated water is recovered using an oil/water separator. The contaminated water is ozonated prior to oil/water separation to aid in oil recovery. The water then flows through a filter to remove any fine particles. After the particles

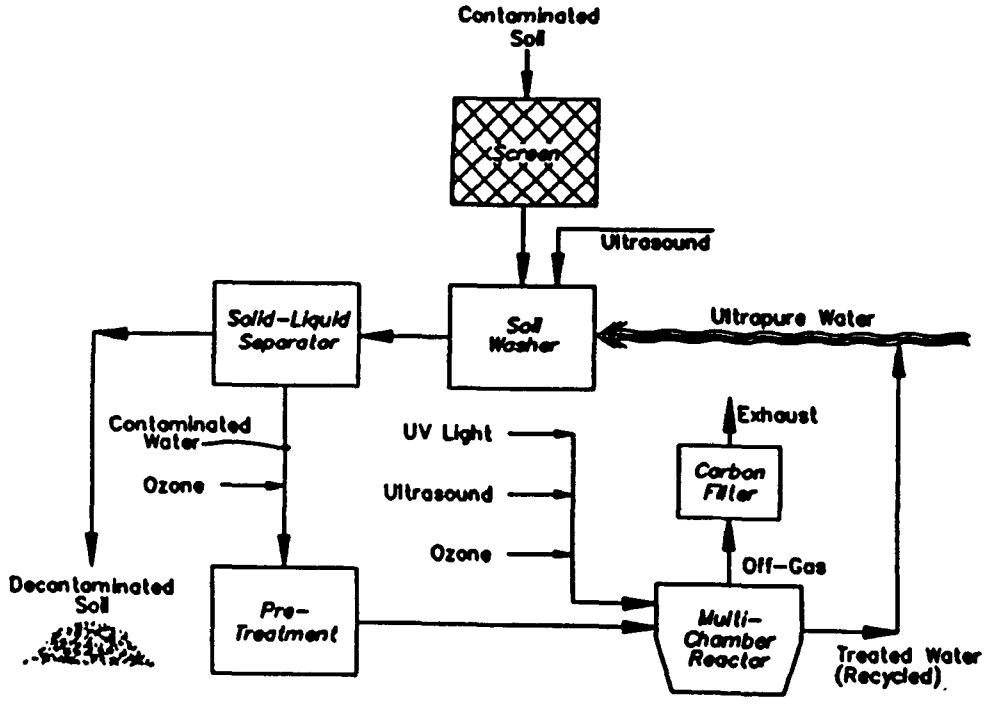


Figure 1. Excaliber Treatment System Flow Diagram.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles EPA/540/5-90/006 (1990).

are filtered, the water flows through a carbon filter and a deionizer to reduce the contaminant load on the multichamber reactor.

In the multichamber reactor, ozone gas, ultraviolet light, and ultrasound are applied to the contaminated water. Ultraviolet light and ultrasound catalyze the oxidation of contaminants by ozone. The treated water (ultrapure water) flows out of the reactor to a storage tank and is reused to wash another batch of soil. If makeup water is required, additional ultrapure water is generated on-site by treating tap water with ozone and ultrasound.

The treatment system is also equipped with a carbon filter to treat the off-gas from the reactor. The carbon filters are biologically activated to regenerate the spent carbon in-situ.

System capacities range from one cubic foot of solids per hour, with a water flow rate of one gallon per minute; to 27 cubic yards of solids per hour, with a water flow rate of 50 gallons per minute. The treatment units available for the SITE demonstration can treat 1 to 5 cubic yards of solids per hour.

WASTE APPLICABILITY:

This technology can be applied to soils, solids, sludges, leachates and ground water containing organics such as PCB, PCP, pesticides and herbicides, dioxins, and inorganics, including cyanides. The technology could effectively treat total contaminant concentrations ranging from 1 ppm to 20,000 ppm. Soils and solids greater than 1 inch in diameter need to be crushed prior to treatment.

STATUS:

The Excalibur technology was accepted into the SITE demonstration program in July, 1989. The Coleman-Evans site in Jacksonville, FL has been tentatively scheduled for a SITE demonstration in late 1990.

FOR FURTHER INFORMATION:

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Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles EPA/540/5-90/006 (1990).

United States Environmental Protection Agency	Office of Emergency and Remedial Response Washington, DC 20460	Office of Research and Development Cincinnati, OH 45268
Superfund	EPA/540/2-90/017	September 1990

Engineering Bulletin
EPA Soil Washing Treatment

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants as a principal element." The Engineering Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial investigation scoping needs. Addenda will be issued periodically to update the original bulletins.

Abstract

Soil washing is a water-based process for mechanically scrubbing soils ex-situ to remove undesirable contaminants. The process removes contaminants from soils in one of two ways: by dissolving or suspending them in the wash solution (which is later treated by conventional wastewater treatment methods) or by concentrating them into a smaller volume of soil through simple particle size separation techniques (similar to those used in sand and gravel operations). Soil washing systems incorporating both removal techniques offer the greatest promise for application to soils contaminated with a wide variety of heavy metal and organic contaminants.

The concept of reducing soil contamination through the use of particle size separation is based on the finding that most organic and inorganic contaminants tend to bind, either chemically or physically, to clay and silt soil particles. The silt and clay, in turn, are attached to sand and gravel particles by physical processes, primarily compaction and adhesion. Washing processes that separate the fine (small) clay and silt particles from the coarser sand and gravel soil particles effectively separate and concentrate the contaminants into a smaller volume of soil that can be further treated or disposed. The clean, larger fraction can be returned to the site for continued use. This set of assumptions forms the basis for the volume-reduction concept upon which most soil washing technology applications are being developed.

At the present time, soil washing is used extensively in Europe and has had limited use in the United States. During 1986-1989, the technology was one of the selected source control remedies at eight Superfund sites.

The final determination of the lowest cost alternative will be more site-specific than process equipment dominated. Vendors should be contacted to determine the availability of a unit for a particular site. This bulletin provides information on the technology applicability, the types of residuals resulting from the use of the technology, the latest performance data, site requirements, the status of the technology, and where to go for further information.

Technology Applicability

Soil washing can be used either as a stand-alone technology or in combination with other treatment technologies. In some cases, the process can deliver the performance needed to reduce contaminant concentrations to acceptable levels and, thus, serve as a stand-alone technology. In other cases, soil washing is most successful when combined with other technologies. It can be cost-effective as a pre-processing step in reducing the quantity of material to be processed by another technology such as incineration; it also can be used effectively to transform the soil feedstock into a more homogeneous condition to augment operations in the subsequent treatment system. In general, soil washing is effective on coarse sand and gravel contaminated with a wide range of organic, inorganic, and reactive contaminants. Soils containing a large amount of clay and silt typically do not respond well to soil washing, especially if it is applied as a stand-alone technology.

A wide variety of chemical contaminants can be removed from soils through soil washing applications. Removal efficiencies depend on the type of contaminant as well as the type of soil. Volatile organic contaminants often are easily removed from soil by washing; experience shows that volatiles can be removed with 90-99 percent efficiency or more. Semivolatile organics

may be removed to a lesser extent (40-90 percent) by selection of the proper surfactant. Metals and pesticides, which are more insoluble in water, often require acids or chelating agents for successful soil washing. The process can be applicable for the treatment of soils contaminated with specific listed Resource Conservation and Recovey Act (RCRA) wastes and other hazardous wastes including wood-preserving chemicals (pentachlorophenol, creosote), organic solvents, electroplating residues (cyanides, heavy metals), paint sludges (heavy metals), organic chemicals production residues, pesticides and pesticides production residues, and petroleum/oil residues [1, p. 659][2, p. 15][4][7 through 13]*.

The effectiveness of soil washing for general contaminant groups and soil types is shown in Table 1 [1, p. 659][3, p. 13][15, p.1]. Examples of constituents within contaminant groups are provided in Reference 3, "Technology Screening Guide For Treatment of CERCLA Soils and Sludges." This table is based on currently available information or professional judgment where definitive information is currently inadequate or unavailable. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the treatment efficiency achieved will be acceptable at other sites. For the ratings used in this table, good to excellent applicability means the probability is high that soil washing will be effective for that particular contaminant and matrix. Moderate to marginal applicability indicates situations where care needs to be exercised in choosing the soil washing technology. When not applicable is shown, the technology will probably not work for that particular combination of contaminant group and matrix. Other sources of general observations and average removal efficiencies for different treatability groups are the Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions" (OSWER Directive 9347.3-06FS), [16] and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-07FS) [17].

Information on cleanup objectives as well as the physical and chemical characteristics of the site soil and its contaminants is necessary to determine the potential performance of this technology and the requirements for waste preparation and pretreatment. Treatability tests are also required at the laboratory screening, bench-scale and/or pilot-scale level(s) to determine

Table 1
Applicability of Soil Washing on General Contaminant Groups for Various Soils

	Contaminant Groups	*Matrix* *Sandy/ Gravelly Soils*	*Silty/Clay Soils*
Organic	Halogenated volatiles	■	▼
	Halogenated semivolatiles	▼	▼
	Nonhalogenated volatiles	■	▼
	Nonhalogenated semivolatiles	▼	▼
	PCBs	▼	▼
	Pesticides (halogenated)	▼	▼
	Dioxins/Furans	▼	▼
	Organic cyanides	▼	▼
	Organic corrosives	▼	▼
Inorganic	Volatile metals	■	▼
	Nonvolatile metals	■	▼
	Asbestos	□	□
	Radioactive materials	▼	▼
	Inorganic corrosives	▼	▼
	Inorganic cyanides	▼	▼
Reactive	Oxidizers	▼	▼
	Reducers	▼	▼

■ Good to Excellent Applicability: High probability that technology will be successful

▼ Moderate to Marginal Applicability: Exercise care in choosing technology

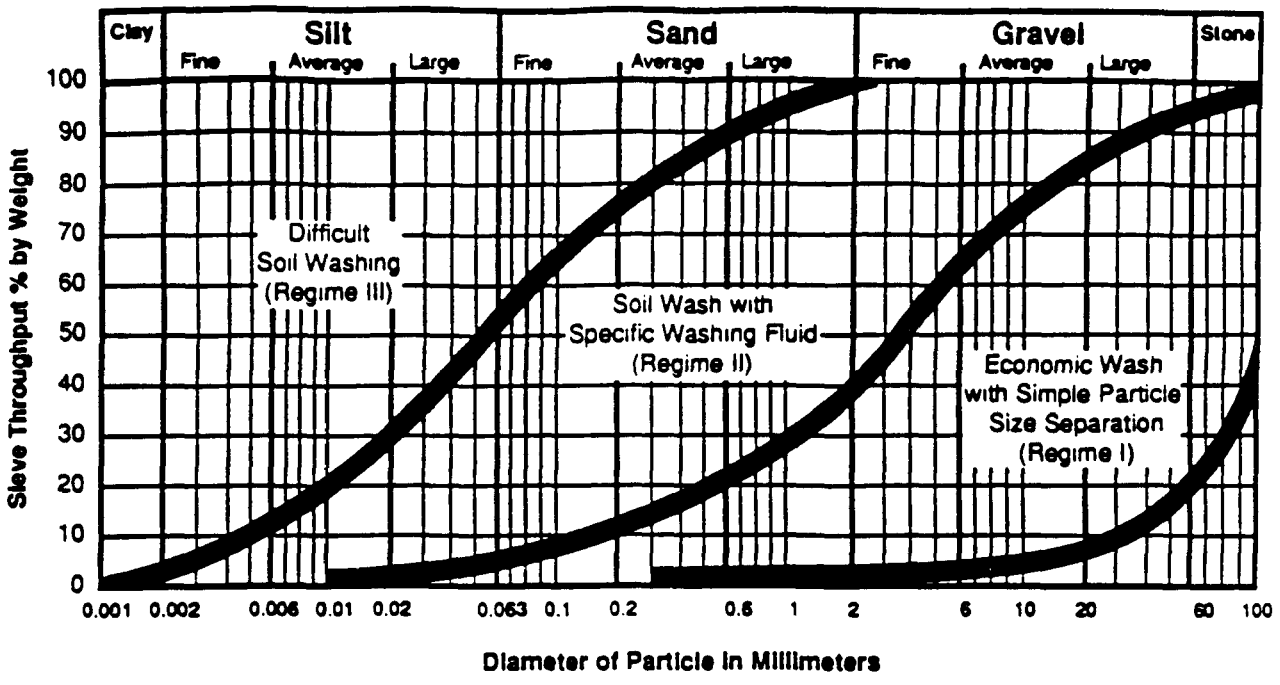
□ Not Applicable: Expert opinion that technology will not work

* [reference number, page number]

Table 2
Waste Soil Characterization Parameters

Parameter	*Purpose and Comment*
Key Physical	
Particle size distribution:	
>2 mm	Oversize pretreatment requirements
0.25-2 mm	Effective soil washing
0.063-0.25 mm	Limited soil washing
<0.063 mm	Clay and silt fraction—difficult soil washing
Other Physical	
Type, physical form, handling properties	Affects pretreatment and transfer requirements
Moisture content	Affects pretreatment and transfer requirements
Key Chemical	
Organics Concentration Volatility Partition coefficient	Determine contaminants and assess separation and washing efficiency, hydrophobic interaction, washing fluid compatibility, changes in washing fluid with changes in contaminants. May require preblending for consistent feed. Use the jar test protocol to determine contaminant partitioning.
Metals	Concentration and species of constituents (specific jar test) will determine washing fluid compatibility, mobility of metals, posttreatment.
Humic acid	Organic content will affect adsorption characteristics of contaminants on soil. Important in marine/wetland sites.
Other Chemical	
pH, buffering capacity	May affect pretreatment requirements, compatibility with equipment materials of construction, wash fluid compatibility.

Figure 1
Soil Washing Applicable Particle Size Range



the feasibility of the specific soil washing process being considered and to understand waste preparation and pretreatment steps needed at a particular site. If bench-test results are promising, pilot-scale demonstrations should normally be conducted before final commitment to full-scale implementation. Treatability study procedures are explained in the EPA's forthcoming document entitled "Superfund Treatability Study Protocol: Bench-Scale Level of Soils Washing for Contaminated Soils" [14].

Table 2 contains physical and chemical soil characterization parameters that must be established before a treatability test is conducted on a specific soil washing process. The parameters are defined as either "key" or "other" and should be evaluated on a site-specific basis. Key parameters represent soil characteristics that have a direct impact on the soil washing process. Other parameters should also be determined, but they can be adjusted prior to the soil washing step based on specific process requirements. The table contains comments relating to the purpose of the specific parameter to be characterized and its impact on the process [6, p. 90][14, p. 35].

Particle size distribution is the key physical parameter for determining the feasibility of using a soil washing process. Although particle size distribution should not become the sole reason for choosing or eliminating soil washing as a candidate technology for remediation, it can provide an initial means of screening for the potential use of soil washing. Figure 1 presents a simplistic particle size distribution range of curves that illustrate a general screening definition for soil washing technology.

In its simplest application, soil washing is a particle size separation process that can be used to segregate the fine fractions from the coarse fractions. In Regime I of Figure 1, where coarse soils are found, the matrix is very amenable to soil washing using simple particle size separation.

Most contaminated soils will have a distribution that falls within Regime II of Figure 1. The types of contaminants found in the matrix will govern the composition of the washing fluid and the overall efficiency of the soil washing process.

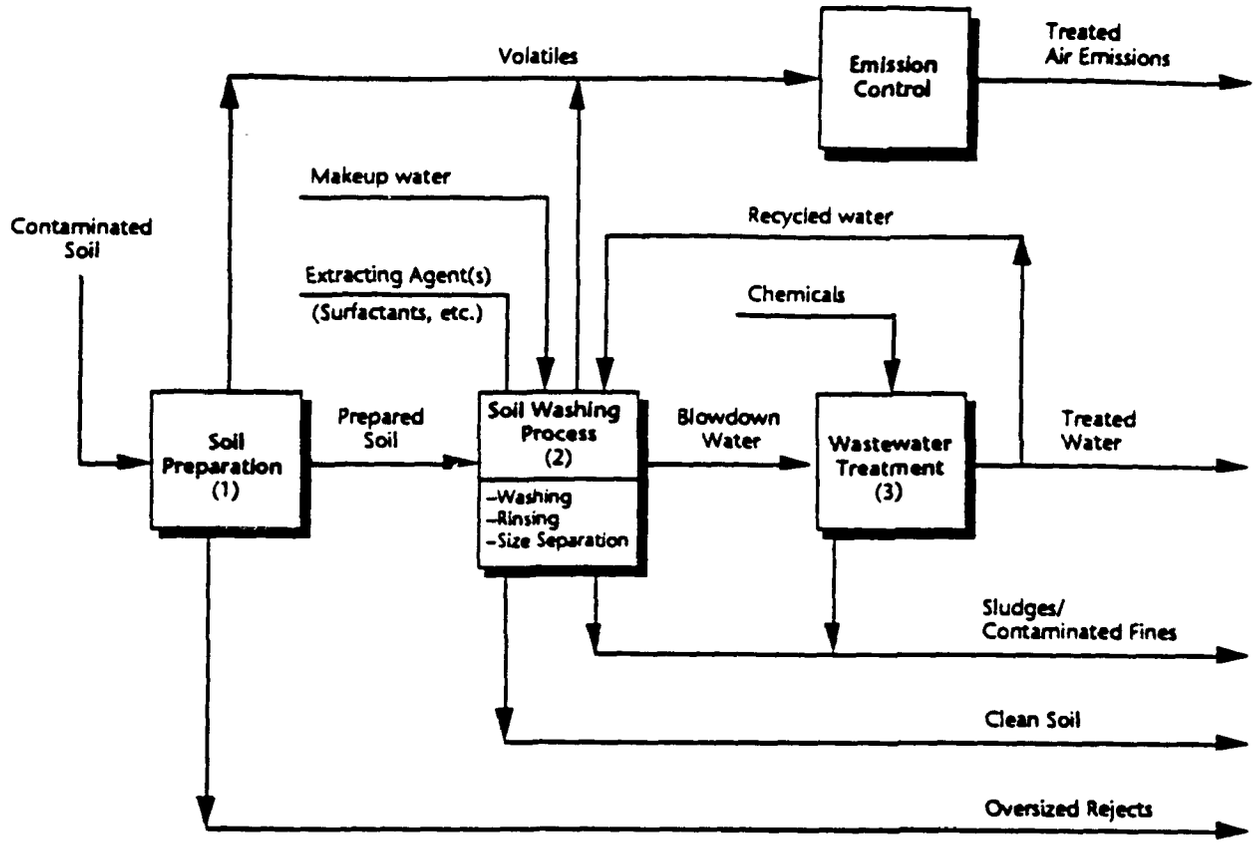
In Regime III of Figure 1, soils consisting largely of finer sand, silt, and clay fractions, and those with high humic content, tend to contain strongly adsorbed organics that generally do not respond favorably to systems that work by only dissolving or suspending contaminants in the wash solution. However, they may respond to soil washing systems that also incorporate a particle size separation step whereby contaminants can be concentrated into a smaller volume.

Limitations

Contaminants in soils containing a high percentage of silt- and clay-sized particles typically are strongly adsorbed and difficult to remove. In such cases, soil washing generally should not be considered as a stand-alone technology.

Hydrophobic contaminants generally require surfactants or organic solvents for their removal from soil. Complex mixtures of contaminants in the soil (such as a mixture of metals, nonvolatile organics, and semivolatile organics) and

Figure 2
Aqueous Soil Washing Process



frequent changes in the contaminant composition in the soil matrix make it difficult to formulate a single suitable washing fluid that will consistently and reliably remove all of the different types of contaminants from the soil particles. Sequential washing steps may be needed. Frequent changes in the wash formulation and/or the soil/wash fluid ratio may be required [3, p. 76][14, p. 7].

While washwater additives such as surfactants and chelants may enhance some contaminant removal efficiencies in the soil washing portion of the process, they also tend to interfere with the downstream wastewater treatment segments of the process. The presence of these additives in the washed soil and in the wastewater treatment sludge may cause some difficulty in their disposal [14, p. 7][15, p. 1]. Costs associated with handling the additives and managing them as part of the residuals/wastewater streams must be carefully weighed against the incremental improvements in soil washing performance that they may provide.

Technology Description

Figure 2 is a general schematic of the soil washing process [1, p. 657][3, p. 72][15, p. 1].

Soil preparation (1) includes the excavation and/or moving of contaminated soil to the process where it is normally screened to remove debris and large objects. Depending upon the technology and whether the process is semibatch or continuous, the soil may be made pumpable by the addition of water.

A number of unit processes occur in the soil washing process (2). Soil is mixed with washwater and possibly extraction agent(s) to remove contaminants from soil and transfer them to the extraction fluid. The soil and washwater are then separated, and the soil is rinsed with clean water. Clean soil is then removed from the process as product. Suspended soil particles are recovered directly from the spent washwater, as sludge, by gravity means, or they may be removed by flocculation with a selected polymer or chemical, and then separated by gravity. These solids will most likely be a smaller quantity but carry higher levels of contamination than the original soil and, therefore, should be targeted for either further treatment or secure disposal. Residual solids from recycle water cleanup may require post-treatment to ensure safe disposal or release. Water used in the soil washing process is treated by conventional wastewater treatment processes to enable it to be recycled for further use.

Wastewater treatment (3) processes the blowdown or discharge water to meet regulatory requirements for heavy metal content, organics, total suspended solids, and other parameters. Whenever possible, treated water should be recycled to the soil washing process. Residual solids, such as spent ion exchange resin and carbon, and sludges from biological treatment may require post-treatment to ensure safe disposal or release.

Vapor treatment may be needed to control air emissions from excavation, feed preparation, and extraction; these emissions are collected and treated, normally by carbon adsorption or incineration, before being released to the atmosphere.

Process Residuals

There are four main waste streams generated during soil washing: contaminated solids from the soil washing unit, wastewater, wastewater treatment sludges and residuals, and air emissions.

Contaminated clay fines and sludges resulting from the process may require further treatment using acceptable treatment technologies (such as incineration, low temperature desorption, solidification and stabilization, biological treatment, and chemical treatment) in order to permit disposal in an environmentally safe manner [16]. Blowdown water may need treatment to meet appropriate discharge standards prior to release to a local, publicly owned wastewater treatment works or receiving stream. To the maximum extent practical, this water should be recovered and reused in the washing process. The wastewater treatment process sludges and residual solids, such as spent carbon and spent ion exchange resin, must be appropriately treated before disposal. Any air emissions from the waste preparation area or the washing unit should be collected and treated, as appropriate to meet applicable regulatory standards.

Site Requirements

Access roads are required for transport of vehicles to and from the site. Typically, mobile soil washing process systems are located onsite and may occupy up to 4 acres for a 20 ton/hour unit; the exact area will depend on the vendor system selected, the amount of soil storage space, and/or the number of tanks or ponds needed for washwater preparation and wastewater treatment.

Typical utilities required are water, electricity, steam, and compressed air. An estimate of the net (consumed) quantity of local water required for soil washing, assuming water cleanup and recirculation, is 130,000-800,000 gallons per 1,000 cubic yards (2,500,000 lbs.) of soil (approximately 0.05-0.3 gallons per pound).

Because contaminated soils are usually considered hazardous, their handling requires that a site safety plan be developed to provide for personnel protection and special handling measures during soil washing operations.

Moisture content of soil must be controlled for consistent handling and treatment; this can be accomplished, in part, by covering excavation, storage, and treatment areas.

Fire hazard and explosion considerations should be minimal, since the soil washing fluid is predominantly water. Generally, soil washing does not require storing explosive, highly reactive materials.

Climatic conditions such as annual or seasonal precipitation cause surface runoff and water infiltration. Berms, dikes, or other runoff control methods may be required. Cold weather freezing must also be considered for aqueous systems and soil excavation operations.

Proximity to a residential neighborhood will affect plant noise requirements and emissions permitted in order to minimize their impact on the population and meet existing rules and regulations.

If all or part of the processed soil is to be redeposited at the site, storage areas must be provided until analytical data are obtained that verifies that treatment standards have been achieved. Onsite analytical capability could expedite the storage/final disposition process. However, soil washing might be applied to many different contaminant groups. Therefore, the analytes that would have to be determined are site specific, and the analytical equipment that must be available will vary from site to site.

Performance Data

The performances of soil washing processes currently shown to be effective in specific applications are listed in Table 3 [1][2][4][7 through 13]. Also listed are the range of particle size treated, contaminants successfully extracted, byproduct wastes generated, extraction agents used, major extraction equipment for each system, and general process comments.

The data presented for specific contaminant removal effectiveness were obtained from publications developed by the respective soil washing system vendors. The quality of this information has not been determined.

RCRA Land Disposal Restrictions (LDRs) that require treatment of wastes to best demonstrated available technology (BDAT) levels prior to land disposal may sometimes be determined to be applicable or relevant and appropriate requirements (ARARs) for CERCLA response actions. The soil washing technology can produce a treated waste that meets treatment levels set by BDAT, but may not reach these treatment levels in all cases. The ability to meet required treatment levels is dependent upon the specific waste constituents and the waste matrix. In cases where soil washing does not meet these levels, it still may, in certain situations, be selected for use at the site if a treatability variance establishing alternative treatment levels is obtained. EPA has made the treatability variance process available in order to ensure that LDRs do not unnecessarily restrict the use of alternative and innovative treatment technologies. Treatability variances may be justified for handling complex soil and debris matrices. The following guides describe when and how to seek a treatability variance for soil and debris: Superfund LDR Guide #6A, "Obtaining a Soil

and Debris Treatability Variance for Remedial Actions" (OSWER Directive 9347.3-06FS) [16], and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-07FS) [17]. Another approach could be to use other treatment techniques in series with soil washing to obtain desired treatment levels.

Technology Status

During 1986-1989, soil washing technology was selected as one of the source control remedies at eight Superfund sites: Vineland Chemical, New Jersey; Koppers Oroville Plant, California; Cape Fear Wood Preserving, North Carolina; Ewan Property, New Jersey; Tinkam Garage, New Hampshire; United Scrap, Ohio; Koppers/Texarkana, Texas; and South Cavalcade, Texas [18].

A large number of vendors provide a soil washing technology. Table 3 shows the current status of the technology for 14 vendors. The front portion of the table indicates the scale of equipment available from the vendor and gives some indication of the vendor's experience by showing the year it began operation.

Processes evaluated or used for site cleanups by the EPA are identified separately by asterisks in the Proprietary Vendor Process/EPA column in Table 3.

The following soil washing processes that are under development have not been evaluated by the EPA or included in Table 3. Environmental Group, Inc. of Webster, Texas, has a process that reportedly removes metals and oil from soil. Process efficiency is stated as greater than 99 percent for lead removal from soils cleaned in Concord, California; greater than 99 percent for copper, lead, and zinc at a site in Racine, Wisconsin; and 94 percent for PCB removal on a Morrisc Knudsen Company project. The process does not appear t. separate soil into different size fractions. Detailed information on the process is not available. Consolidated Sludge Company of Cleveland, Ohio, has a soil washing system planned that incorporates their Mega-sludge Press at the end of the process for dewatering solids. The system has not yet been built.

Vendor-supplied treatment costs of the processes reviewed ranged from $50 to $205 per ton of feed soil. The upper end of the cost range includes costs for soil residue disposal.

EPA Contact

Technology-specific questions regarding soil washing may be directed to:

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EXHIBIT 7 - ENGINEERING BULLETIN: SOIL WASHING TREATMENT (continued)

Table 3. Summary of Performance Data and Technology Status - Part I

Proprietary Vendor Process/EPA	Highest Scale of Operation	Year Operation Began	Range of Particle Size Treated	Contaminants Extracted From Soil	Extraction Agent(s)
U.S. Processes					
(1) SOIL CLEANING COMPANY OF AMERICA [5][15, p. 2]	Full scale 15 tons/hr	1988	Bulk soil	Oil and grease	Hot water with surfactant
(2)* BIOTROL SOIL TREATMENT SYSTEM (BSTS) [4, p. 6][12]	Pilot scale 500 lbs/hr	Fall, 1987	Above clay size and below 0.5 in. Some cleaning of fine particles in bio-reactor	Organics - pentachlorophenol, creosote, naphthalene, pyrene, fluorene, etc.	Proprietary conditioning chemicals
(3) EPA'S MOBILE COUNTER-CURRENT EXTRACTOR [9][5, p. 5]	Pilot scale 4.1 tons/hr	Modified with drum washer and shakedown-1982 Full Scale-1986	2-25 mm in drum washer <2 mm in four-stage extractor	Soluble organics (phenol, etc.) Heavy metals (Pb, etc.)	Various solvents, additives, surfactants, redox acids and bases Chelating agent (EDTA)
(4)* EPA'S FIRST GENERATION PILOT DRUM SCREEN WASHER [10, p. 8]	Pilot scale	1988	Oversize (>2 mm) removed prior to treatment	Petroleum hydrocarbons	Biodegradable surfactant (aqueous slurry)
(5)* MTA REMEDIAL RESOURCES [11][15, p. 2]	Bench scale	N/A	Oversize removed prior to treatment	Organics (oil) Heavy metals (inorganics) removed using counter-current decantation with leaching	Surfactants and alkaline chemicals added upstream of froth flotation cells. Acid for leaching.
Non U.S. Processes					
(6) ECOTECHNIEK BV [2, p. 17]	Commercial 100 ton/hr max	1982	Sandy soil	Crude oil	None. Water-sand slurry heated to 90°C max. with steam.
(7) BODEMSANERING NEDERLAND BV (BSN) [2, p. 17]	Commercial 20 ton/hr	1982	>100 mm removed No more than 20% <63 µm Sludge <30 µm not cleaned	Oil from sandy soil	None. Uses high pressure water jet for soils washing.
(8) HARBAUER [2, p. 20][7, p. 5]	Commercial 15-20 tons/hr	Lab - 1985 Commercial -1986 With fines removal - 1987	15 µm - 5mm Pre-treatment: coarse screens, electromagnet blade washer	Mostly organics Limited heavy metals removal experience	Hydraulically produced oscillation/ vibration Surfactants Acid/base
(9) HWZ BODEMSANERING BV [2, p. 17]	Commercial 20-25 tons/hr	1984	<10 mm and >63 µm	Cyanide, Chlorinated HC, some heavy metals, PNA	Sodium Hydroxide to adjust pH Surfactants
(10) HEIJMAN MILIEUTECHNIEK BV [2,p.17][7, p. 6]	Pilot scale 10-15 tons/hr	1985	<10 mm and no more than 30% <63 µm	Cyanide, heavy metals, mineral oil (water immiscible hydrocarbons)	Proprietary extraction agents. Hydrogen Peroxide (H_2O_2) added to react with extracted CN to form CO_2 and NH_3
(11) HEIDEMIJ FROTH FLOTATION [7, p. 8]	Full scale	N/A	<4 mm and no more than 20% <50 µm	Cyanide, heavy metals, chlorinated HCs, oil, toluene, benzene, pesticides, etc.	Proprietary Surfactants and other proprietary chemicals

*Process evaluated or used for site cleanup by the EPA. N/A = Not available.

EXHIBIT 7 - ENGINEERING BULLETIN: SOIL WASHING TREATMENT (continued)

Table 3. Summary of Performance Data and Technology Status - Part I (continued)

Proprietary Vendor Process/EPA	Highest Scale of Operation	Year Operation Began	Range of Particle Size Treated	Contaminants Extracted From Soil	Extraction Agent(s)
Non U.S. Processes (continued)					
(12) EWH ALSEN - BREITENBURG Dekomat System [2, p. 20]	Pilot scale 8-10 cu. m/hr	N/A	<80 mm Clays treated offsite	Oil from sandy soil	Proprietary
(13) TBSG INDUSTRIEVERTIETUNGEN Oil Crep I System [7, p. 7]	Pilot scale	1986	Sand <50 mm Particles <100 µm treated offsite	Hydrocarbon and oil	Proprietary combination of surfactants, solvents, and aromatic hydrocarbons
(14) KLOCKNER UMWELTECHNIK Jet-Modified BSN [2, p. 20]	Pilot scale	N/A	No more than 20% <63 µm	Aliphatics and aromatics with densities < water, volatile organics, some other hydrocarbons	None. Soil blasted with a water jet (at 5,075 psi)

Table 3. Summary of Performance Data and Technology Status - Part II

Proprietary Vendor Process/EPA	Byproduct Wastes Generated	Extraction Equipment	Efficiency of Contaminant Removal	Additional Process Comments
U.S. Processes				
(1) SOIL CLEANING OF AMERICA	Wet oil	Screw conveyors	Contaminant: Oil and grease; Removal Efficiency %: 50-83; Residual ppm: 250-600	Three screw conveyors operated in series, hot water with surfactant injected into each stage. Final soil rinse on a fourth screw conveyor.
(2) * BIOTROL SOIL TREATMENT SYSTEM (BSTS)	Oil and grease Sludge from biological treatment	Agitated conditioning tank Froth flotation Slurry bioreactor	For the case presented: 90-95% for Pentachlorophenol; to residuals <115 ppm. 85-95% for most other organics; to residuals <1 ppm.	Dewatered clays and organics to be treated offsite by incineration, solidification, etc. Washed soil was approx. 78% of feed. Therefore, significant volume reduction was achieved.
(3) EPA's MOBILE COUNTER-CURRENT EXTRACTOR	Clay fraction Recovered organics (extractor skimmings) Spent carbon (oversize)	Drum screen Water knife Soil scrubber 4-Stage Counter-current chemical extractor	Contaminant: Phenol; Removal Efficiency %: 90 from in. soil, 80 from or. soil; Residual ppm: 1, 96 Contaminant: As_2O_3; Removal Efficiency %: 50-80; Residual ppm: 0.5-1.3	Clay fraction treated elsewhere.
(4) * EPA's FIRST GENERATION PILOT DRUM SCREEN WASHER (PDSW)	Sludge Flocculated fines	Drum screen washer	Contaminant: Oil and grease; Soil Size Fraction mm: 0.25-2, <0.25; Removal Effic. %: 99, 90; Residual ppm: <5, 2400	Process removal efficiency increases if extracting medium is heated. Install wet classifiers beneath the PDSW to remove waste water from treated soil. Auger classifiers are required to to discharge particles effectively.
(5)* MTA REMEDIAL RESOURCES (MTARR) Froth Flotation	Flocculation froth	Reagent blend tank Flotation cells Counter-current decantation	Contaminant: Volatile organics; Removal Efficiency %: 98-99+; Residual ppm: < 50 Contaminant: Semivolatile organics; Removal Efficiency %: 98-99+; Residual ppm: < 250 Contaminant: Most fuel products; Removal Efficiency %: 98-99+; Residual ppm: < 2200	Flotation cells linked by underflow weir gates. Induced air blown down a center shaft in each cell. Continuous flow operation. Froth contains 5-10 wt% of feed soil.

*Process evaluated or used for site cleanup by the EPA. N/A = Not available.

Table 3. Summary of Performance Data and Technology Status - Part II (continued)

Proprietary Vendor Process/EPA	Byproduct Wastes Generated	Extraction Equipment	Efficiency of Contaminant Removal	Additional Process Comments
Non U S Processes				
(6) ECOTECHNIEK BV	Wet oil	Jacketed, agitated tank	About 90% 20,000 ppm residual oil	Effectiveness of process dependent on soil particle size and type of oil to be separated.
(7) BODEMSANERING NEDERLAND BV (BSN)	Oil/organics recovered from wastewater fines	Water jet	Selected results: Contaminant / Removal Efficiency % / Residual ppm Aromatics >81 >45 PNAs 95 15 Crude oil 97 2300	No comments
(8) HARBAUER OF AMERICA	Carbon which may contain contaminants	Conditioning tank Low frequency vibration unit	Contaminant / Removal Efficiency % / Residual ppm Organic-Cl ND Tot. organics 96 159-201 Tot. phenol 86-94 7-22.5 PAH 86-90 91.4-97.5 PCB 84-88 0.5-1.3	Vibrating screw conveyor used. Cleaned soil separated from extractant liquor in stages; coarse soil by sedimentation, medium fraction in hydroclone, fines (15-20 µm) by vacuum filter press.
(9) HWZ BODEMSANERING BV	Fines Sludge containing iron cyanide Large particles — carbon, wood, grass	Scrubber (for caustic addition) Upflow classifier	Contaminant / Removal Efficiency % / Residual ppm CN 95 5-15 PNAs 98 15-20 Chlorin-HC 98 <1 Heavy metals 75 75-125	When the fines fraction (<63 µm) is greater than 20%, the process is not economical. HWZ has had some problems in extracting PNAs and oily material.
(10) HEIJMAN MILIEUTECHNIEK BV	Flocculated fines sludge Oil (if any) and silt	Mix tank followed by soils fraction equipment — hydroclones, sieves, tilt plate separators	Contaminant / Removal Efficiency % / Residual ppm Cyanide 93-99 <15 Heavy metal cations approx. 70 <200	Process works best on sandy soils with a minimum of humus-like compounds. Because no sand or charcoal filters are employed by Heijmans, the system does not remove contaminants such as chlorinated hydrocarbons.
(11) HEIDEMIJ FROTH FLOTATION	Contaminated float	Conditioning tank Froth flotation tanks	Contaminant / Removal Efficiency % / Residual ppm Cyanide >95 5 Heavy metals >90 avg >150 Chlorin-HC >99 0.5 Oil >99 20	Process has broad application for removing hazardous materials from soil. Most experience has been on a laboratory scale.
(12) EWH ALSEN - BREITENBURG Dekomat System	Recovered oil Flocculated fines (sludge)	High-shear stirred tank	About 95% oil removed	Cleaned soil from high shear stirred tank is separated into fractions using vibrating screens, screw classifiers, hydroclones, and sedimentation tanks.
(13) TBSG INDUSTRIEVEITIET-UNGEN Oil Crep I System	Oil phase containing Oil Crep I	Screw mixer followed by a rotating separation drum for oil recovery	>95% Removal of hydrocarbons has been achieved. Results are influenced by other contaminants present.	Oil Crep system was used successfully in Flensburg, FRG (in 1986) to remove PCBs, PAHs, and other hydrocarbons.
(14) KLOCKNER UMWELTECHNIK High Pressure Water Jet-Modified BSN	Oil/organics recovered from wastewater fines Sludge	Water jet - circular nozzle arrangement	Selected results: Contaminant / Removal Efficiency % / Residual ppm HC 96.3 82.05 Chlorin-HC >75. <0.01 Aromatics 99.8 <0.02 PAHs 95.4 15.48 Phenol >99.8 <0.01	No comments

*Process evaluated or used for site cleanup by the EPA. N/A = Not available.

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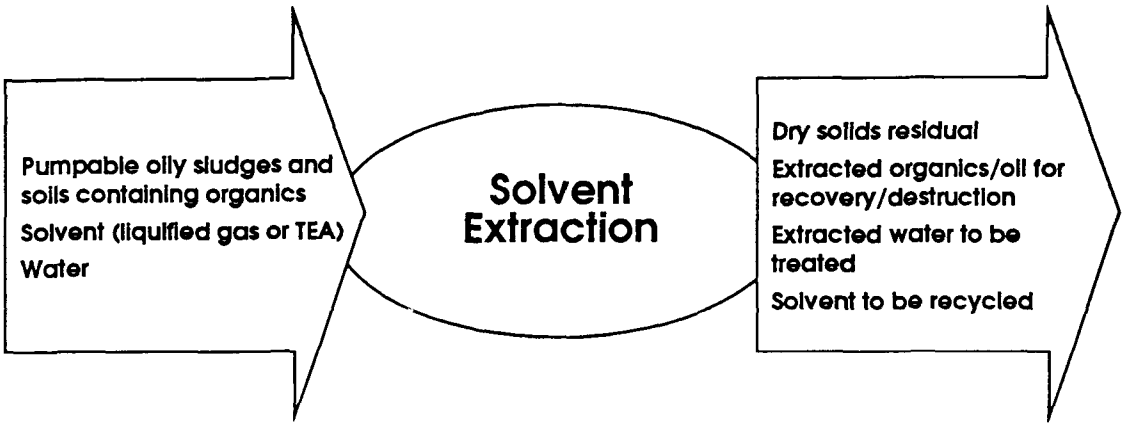
5.0 SOLVENT EXTRACTION

5.1 TECHNOLOGY DESCRIPTION

Solvent extraction uses an organic solvent to separate hazardous organic contaminants from oily-type wastes, soils, sludges, and sediments, thereby reducing the volume of hazardous waste that must be treated. In general, a solvent that preferentially removes hazardous organics is mixed with the contaminated media to transfer contaminants from the media to the solvent phase. The contaminants are then separated from the solvent with a temperature or pressure change and the solvent recycled. Solvent extraction does not destroy wastes, but is generally used as one in a series of unit operations, and can reduce the overall cost of managing a particular site. The process separates the waste into its three constituent fractions: concentrated contaminants, solids, and water.



• Separates and recovers oils and organics

5.2 TECHNOLOGY STATUS

- Solvent extraction has been selected in RODs at five NPL sites in FY 82 to 90. It was selected for two emergency response actions.

- At present, two commercial vendors have solvent extraction systems that have been tested at Superfund sites. The CF Systems (CF) extraction system was demonstrated with the SITE program. The Basic Extractive Sludge Treatment (B.E.S.T.) system, marketed by the Resource Conservation Company (RCC), was used at the CERCLA General Refining Site in Garden City, Florida. Two other vendors have been accepted into the SITE program: Sanivan has been chosen to remediate Pinette's Salvage Yard in Maine and Dehydrotech has been selected for the PAB Oil Site in Louisiana.

- CF has supplied three commercial-scale extraction units and has a Mobile Demonstration Unit for on-site treatability.

- RCC has installed commercial, full-scale units and also has a transportable pilot-scale unit for treating soils and sludges.

5.3 APPLICATIONS

- Targeted organic contaminants for the Superfund sites for which EPA selected solvent extraction sites include PCBs, VOCs, and pentachlorophenol.

- The CF unit uses liquified gas (propane and/or butane) and has been tested at a Superfund site contaminated with PCBs in New Bedford Harbor, Massachusetts, and demonstrated at a Texas wood preserving site. The gases, which are liquified by compression and mixed with the waste in an extractor, are capable of dissolving large quantities of organics. The solvent-organic mixture forms an extract phase which is decanted from remaining solids and water. The solvent-organic mixture goes to a separation vessel where pressure is decreased, the extraction gas (propane/butane) is vaporized and recycled, and the extracted organics are collected.

- The RCC system uses triethylamine (TEA) as the solvent; this was used to treat acidic, oily PCB-contaminated sludges at the General Refining Site. RCC has also constructed a pilot unit to treat nonpumpable wastes such as soils and contaminated sediments. TEA has an interesting property of becoming water soluble at temperatures below 65°F (18°C). The cold TEA is mixed with the waste, the solids are released from the oil/water emulsion, and the solids removed by centrifuge and dried. The solvent-organic fraction is then separated from the water by heating.

5.4 TECHNOLOGY STRENGTHS

- Separates organics from the inorganics that remain in the soil. This allows a determination of the most appropriate method for treating/recycling/ disposing of the separate fractions.
- Produce dry solids as byproduct.
- Can recover oil for reuse.
- Generally not limited by high organics or oil concentrations.

CF Technology Strengths

- Demonstrated greater than 90 percent removal efficiency for PCB in sediments from New Bedford Harbor. Testing was conducted with a pilot-scale unit.
- Treatability tests indicate potential for use on broad variety of organic contaminants.

RCC Technology Strengths

- Wastes do not require heating
- Some heavy metals are converted to the hydroxide form, under alkaline conditions utilized by the process. The metals are converted to a solid form and exit the system with treated solids.
- Sampling at the General Refining Site showed separation efficiencies often exceeding 98 percent for oil, water, and solids. Organics generally concentrated in the oil fraction.

5.5 TECHNOLOGY LIMITATIONS

- Organically bound metals can co-extract with organic pollutants, potentially restricting both treatment and recycle options.
- Water addition may be necessary since wastes must be pumpable.
- Generally least effective on high-molecular-weight organics and very hydrophilic substances.
- Presence of water-soluble detergents and emulsifiers can negatively influence extraction efficiency and treatment throughput.
- Treatment is likely to be necessary for separated water.

CF Technology Limitations

- Uses a solvent gas that is flammable.
- Heat must be supplied to waste feeds less than 60°F.

RCC Technology Limitations

- Uses solvent that is flammable in the presence of oxygen. Thus, the field unit requires a safety system utilizing nitrogen blanketing.
- Uses solvent that is toxic to aquatic life and, depending on the disposal method, will probably need to be removed from the solids prior to disposal.
- May require pH adjustment of waste to a pH of approximately 10.

5.6 POTENTIAL MATERIALS HANDLING REQUIREMENTS

- Excavation is required.
- The waste material must be screened to remove debris and large particles
- Size reduction may be needed to achieve a feed size required by the equipment.
  - The CF Systems' unit requires the feed to be less than 1/8 inch in diameter.
  - The RCC unit can handle material up to 1 inch in diameter.
  - Other solvent extraction technologies require feed material to be no larger than 3/8ths to 1 inch in diameter.
- The pH of the waste may require adjustment. Both the CF process and the RCC process work in alkaline conditions.
  - The RCC unit is effective when the pH is greater than 10.
- Water may be added to the wastes. Solvent extraction processes generally are applied to pumpable wastes. If the contaminated material is not pumpable, water must be added.
- The temperature of the wastes may need adjustment.
  - The CF unit requires the waste material to be warmer than 60 F.
  - The RCC unit works on material that is cooler than 65 F.
- The soil, wash water, and any additives must be mixed to ensure adequate transfer of the contaminants.

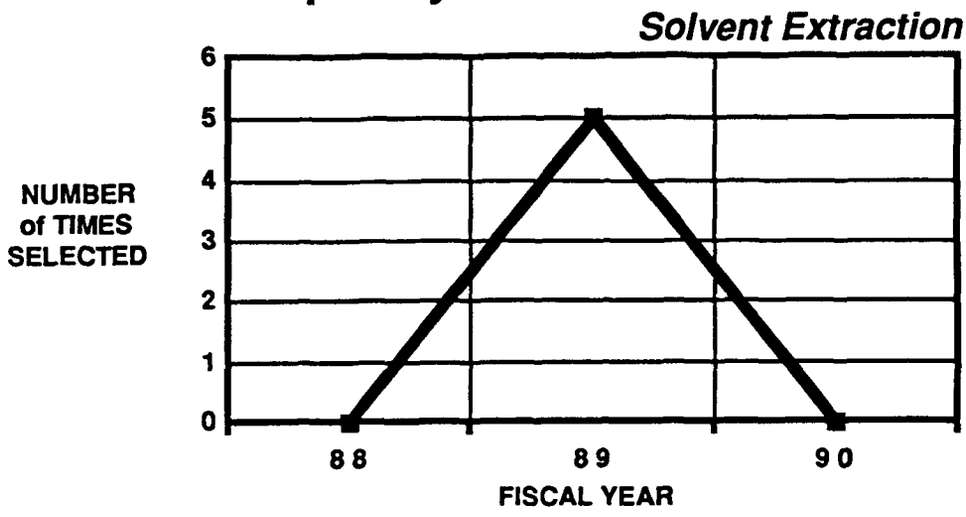
5.7 EXHIBIT 1 - WASTE CHARACTERISTIC TABLE

Waste Type: Soils
Technology: Chemical Extraction

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Presence of elevated levels of volatiles	Volatiles may combine with process solvent, requiring an additional separation step.	Volatile organic analysis
Particle size greater than 1/4 inch	Equipment used in process not capable of handling large particle size. Waste must be pumpable.	Particle size distribution
pH <10	TEA (used in BEST process) is weak base and will exist in solvent form only at approximately pH ≥ 10. Wastes with lower pH must be pretreated to raise pH.	pH measurement
Presence of high amounts of emulsifiers	Adversely impact oil/water phase separation. A greater quantity of solvent is required for appropriate treatment.	Glassware process simulation to measure phase separation characteristics
Metals (e.g., aluminum) or other compounds that undergo strong reactions under highly alkaline conditions	Strong reactions may occur during treatment process because of caustic addition. The adverse reaction may be avoided by using TEA for pH adjustment.	Analysis for aluminum
Types of waste	Materials contaminated with heavy metals not suitable. Wastes that are reactive with carbon dioxide and propane must be pretreated. Wastes containing >200 ppm organics and oil concentration up to 40 percent are acceptable.	Metals analysis

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

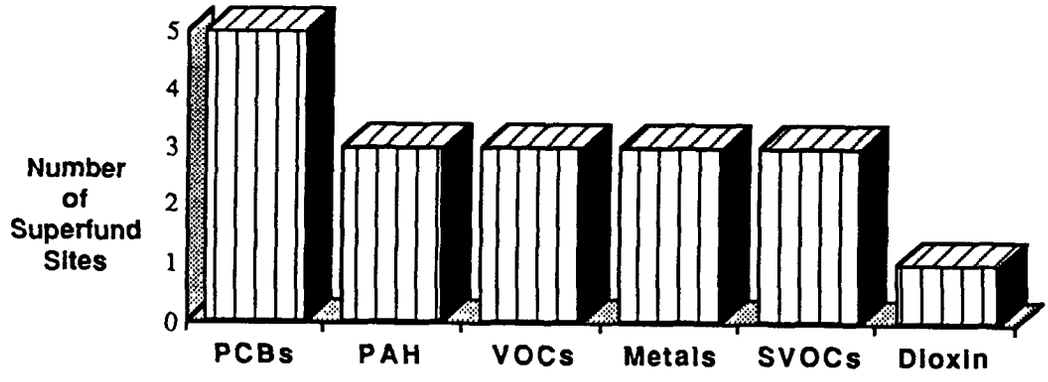
Selection Frequency*



* *Data derived from 1982 - 1990 Records of Decision (RODs) and anticipated design and construction activities.*

September 1991

Contaminants Treated By Solvent Extraction



* *Data derived from 1982 – 1990 Records of Decision (RODs) and anticipated design and construction activities. At some sites, the treatment is for more than one major contaminant.*

EXHIBIT 3 - INNOVATIVE TREATMENT TECHNOLOGIES: SEMI-ANNUAL STATUS REPORT

Solvent Extraction

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
1	Norwood PCBs, MA (09/29/89)	Solvent Extraction	Industrial Waste Dumping	Soil (28,000 cy)	PCBs, PAHs and VOCs (TCE, Trichlorobenzene)	Predesign; Treatability study planned Fall '91; Design completion planned Summer '93	Fund Lead	Jane Downing 617-573-5730 FTS 833-1708
1	O'Connor, ME* (09/27/89)	Solvent Extraction	Salvage & Electrical Transformer Recycling	Soil, Sediments (23,500 cy combined)	PCB, PAHs, and Lead	In design; Design completion planned Spring '93	PRP Lead	Mike Jasinski 617-573-5786 FTS 833-1786
1	Pinette's Salvage Yard, ME* (05/30/89)	Solvent Extraction	Salvage and Vehicle Repair	Soil (2,080 cy)	PCBs, VOCs (Chlorobenzene), SVOCs (Dichlorobenzene and Trichlorobenzene)	Contract awarded Oct. '90; to be installed Spring '92	Fund Lead; Sanivan Group (subcontractor to Sevenson)	Ross Gilleland 617-573-5766 FTS 833-1766
2	Ewan Property, NJ* (09/29/89) Also see Soil Washing	Solvent Extraction (followed by Soil Washing)	Industrial Waste Dumping	Soil (22,000 cy)	VOCs (BTX), SVOCs (Naphthalene and 2,4-dimethylphenol), and Metals	Predesign; Design completion planned Summer '94	PRP Lead	Craig DeBiase 212-264-5393 FTS 264-5393
4	General Refining, GA* (Emergency Response -AM signed 8/13/85)	Basic Extractive Sludge Treatment (BEST)	Waste oil recycling facility	Sludge (2,700 cy), Solids (700 cy) Waste Oil (6,600 gals)	PCBs, Metals (Arsenic, Copper, and Lead)	Project completed; Operatonal 8/86 - 10/86, 1/87 - 2/87	Fund Lead; Resource Conservation Co.	Shane Hitchcock 404-347-3136 FTS 257-3136
6	Traband Warehouse, OK (Emergency Response)	Solvent Extraction	Storage management complex	Concrete and processed sand from sandblasting operation (quantity not available)	PCBs	Project Completed Feb. '89	Fund Lead; Terra-Clean	Pat Hammack 214-655-2270 FTS 255-2270

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Solvent Extraction

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
6	United Creosoting, TX* (09/29/89)	Critical Fluid Extraction	Wood Preserving	Soil (67,000 cy)	PAHs, SVOCs (PCP), and Dioxin	In design; Design completion planned Spring '92	State Lead/ Fund Financed	Deborah Griswold 214-655-6715 FTS 255-6715 Paul Cravens (TX) 512-463-8182

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

United States Environmental Protection Agency | Solid Waste And Emergency Response (OS-220) | Directive 9200 5-253FS November 1989

EPA

Innovative Technology

BEST™ Solvent Extraction Process

TECHNOLOGY DESCRIPTION

Solvent extraction is potentially effective in treating oily sludges and soils by separating the media into three fractions: oil, water, and solids. As the fractions separate, certain contaminants are concentrated into specific phases. For example, PCBs concentrate in the oil fraction, while metals, unless organically bound, accumulate in the solids fraction. Individual phases can then be treated more efficiently. Solvent extraction is capable of processing the oily wastes shown in Table 1. Table 2 lists the effectiveness of solvent extraction on general contaminant groups.

One type of solvent extraction, BEST™ treatment, is a mobile solvent extraction system developed by Resources Conservation Company (RCC). This system uses one or more secondary or tertiary amines (usually triethylamine (TEA)) to separate toxic wastes and oils from sludges or soils. The BEST™ technology is based on the fact that TEA is miscible in water at temperatures below 65°F.

A typical process diagram for the BEST™ process is shown in Figure 1. This process begins by mixing and agitating the cold solvent and sludge or soil in a mixing tank. Oil and water in the feed simultaneously solvate with the cold TEA creating a homogeneous mixture. As the solvent breaks the oil-water-solid bonds, the solids are released from the emulsion. These solids are subsequently removed by centrifuging, which ensures submicron particles are removed. The solids are passed to a second mixing tank where they are washed with additional solvent and centrifuged a second time. The wet solids (about 50% solids by weight) are sent to a dryer where the solvent is vaporized and collected for recycling. Dry solids containing heavy metals may require further treatment before disposal.

The liquids from the first centrifuge, containing the oil and water extracted from the feed, are heated in a series of heat exchangers. As the temperature of the liquids increase, the water separates from the oil-solvent. The oil-solvent fraction is decanted and sent to a stripping column where the solvent is recycled and the oil is discharged for recycling or disposal. The water phase is passed to a second stripping column where residual solvent is recovered for recycling; the water is typically discharged to a local wastewater treatment plant.

An advantage of RCC's facility is the modular capability, allowing on-site treat-

Figure 1: Schematic Diagram of a Typical BEST™ Treatment Facility

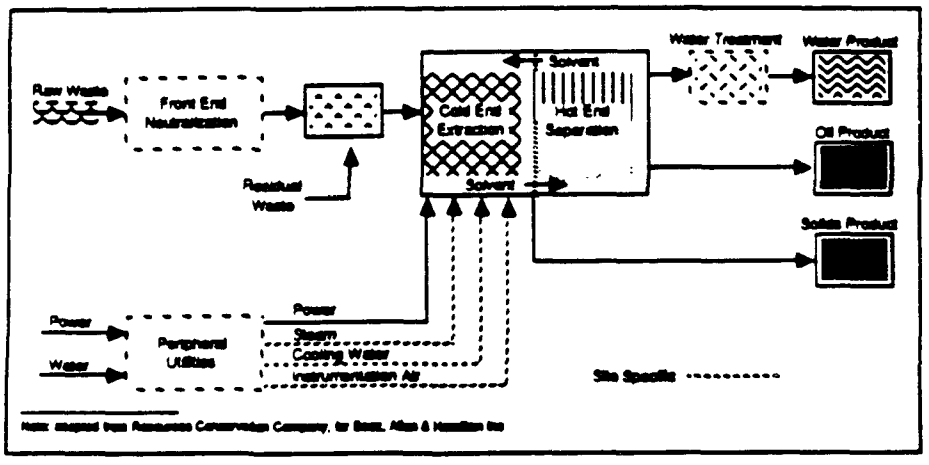


Table 1
Specific Wastes Capable of Treatment Using Solvent Extraction

RCRA Listed Hazardous Wastes
- Creosote-Saturated Sludge
- Dissolved Air Flotation (DAF) Float
- Slop Oil Emulsion Solids
- Heat Exchanger Bundles Cleaning Sludge
- API Separator Sludge
- Tank Bottoms (Leaded)

Non-Listed Hazardous Wastes
- Primary Oil/Solids/Water Separation Sludges
- Secondary Oil/Solids/Water Separation Sludges
- Bio-Sludges
- Cooling Tower Sludges
- HF Alkylation Sludges
- Waste FCC Catalyst
- Spent Catalyst
- Stretford Unit Solution
- Tank Bottoms
- Treated Clays

Table 2
Effectiveness of Solvent Extraction on General Contaminant Groups for Soil and Sludge

	Treatability Groups	Effectiveness: Soil	Effectiveness: Sludge
Organics	Halogenated volatiles	◒	◒
	Halogenated semi-volatiles	◒	●
	Non-halogenated volatiles	◒	◒
	Non-halogenated semi-volatiles	◒	●
	PCBs	◒	●
	Pesticides	◒	◒
	Dioxins/Furans	◒	◒
	Organic cyanides	◒	◒
	Organic corrosives	◒	◒
Inorganics	Volatile metals	○	○
	Non-volatile metals	○	○
	Asbestos	○	○
	Radioactive materials	○	○
	Inorganic corrosives	○	○
	Inorganic cyanides	○	○
Reactive	Oxidizers	X	X
	Reducers	X	X

● Demonstrated Effectiveness ○ No Expected Effectiveness
◒ Potential Effectiveness X Possibly Detrimental

ment. Other advantages of the BEST™ technology include the production of dry solids, the recovery and reuse of oil, and waste volume reduction. BEST™ does not, however, reduce contaminant toxicity. Furthermore, implementation can require complex engineering considerations.

SITE CHARACTERISTICS AFFECTING TREATMENT FEASIBILITY

The BEST™ process is not limited by organics or oil concentrations. Performance, however, can be influenced by the presence of detergents and emulsifiers, low pH materials, and reactivity of the sludge with the solvent. Other factors that affect feasibility and actions to minimize these affects are listed in Table 3. Treatability tests should be conducted to determine the effectiveness of the treatment on specific site conditions.

Table 3
Site-Specific Characteristics and Impacts on BEST™

Characteristics Impacting Process Feasibility	Reasons for Potential Impact	Actions to Minimize Impacts
Presence of elevated levels of volatiles	Volatiles may combine with process solvent	Use an additional separation step
Particle diameter greater than 0.25 inches	Equipment used in process not capable of handling large particles	Screen waste to remove large particles or crush in a hammermill
pH less than 10	TEA (used in extraction process) is weak base and will not exist in solvent form at pH less than 10	Raise pH of waste with caustic soda
Presence of high amounts of emulsifiers	Adversely affect oil/water phase separation	Increase quantity of solvent
Compounds that undergo strong reactions under highly alkaline conditions	Strong reactions may occur during treatment because of caustic addition	Raise pH of waste with TEA instead of caustic soda
Types of waste	Some materials are not suitable for chemical extraction (e.g., highly volatile organics and wastes containing mostly toxic metals)	Conduct pre- and/or post-treatment

TECHNOLOGY CONSIDERATIONS

TEA is flammable in the presence of oxygen, therefore, the treatment system must be sealed from the atmosphere and operated under a nitrogen blanket. Also, TEA is known to be toxic to aquatic life and, depending on the disposal method, may need to be removed from the solids. Prior to treatment it is necessary to raise the pH to greater than 10, creating an environment where TEA is stable. This may be accomplished by adding either sodium hydroxide or TEA. (Sodium hydroxide is more cost-effective, however, TEA is less reactive.) It may also be necessary to add water or solvent to the feed to create a slurry capable of being pumped.

Additionally, pre-treatment may require screening of the feed to ensure that particles are all less than 0.25 inches. Because the equipment is incapable of handling large diameter particles, feed may be passed through a 2-inch screen and subsequently crushed in a 0.2-inch hammermill.

Further treatment of by-products may be necessary before disposal. Specifically, wastewater treatment may include carbon adsorption or biological treatment to remove residual organics. Chemical precipitation also may be required to remove soluble metal contaminants. Free water from sludge ponds may either be treated with the sludge or may be treated separately. In addition, waste oil may either be recycled or reused as fuel. If neither option is viable, the oil should be tested to determine appropriate treatment, storage, or disposal actions. Last, leachate tests should be conducted on residual solids to determine if stabilization is necessary before disposal. Other post-treatment alternatives for solids may include thermal stripping, wet air oxidation, in-situ vitrification, soil washing, and/or glycolate dehalogenation.

RCC quotes the cost of treatability studies to be $4,500 for 1 kg of non-PCB contaminated wastes and $5,500 for 1 kg of waste containing PCBs. These costs include three extractions and do not include organic analyses. Treatment costs range from $90/ton for a large facility treating 200 tons/day to $280/ton for a small facility treating 30 tons/day. More information about RCC can be found in Table 4.

Table 4
BEST™ Vendor Information

Company	Contact	Address
Resources Conservation Co.	Paul McGough	3006 Northup Way Bellevue, WA 98004 (206) 828-2400

Note: BEST™ was developed and patented by Resources Conservation Co

TECHNOLOGY STATUS

The first full-scale BEST™ unit was used at the CERCLA General Refining Site in Garden City, Georgia. Further information is summarized in Table 5. Solvent extraction is the selected remedial action for the Pinette's Salvage site and the F. O'Connor site, both located in Maine; the actual process has not yet been determined.

The BEST™ process has been selected for evaluation under the SITE Program. Formal demonstration and testing is being postponed until the developer has obtained funding for a demonstration at an appropriate site.

OFFICE OF RESEARCH AND DEVELOPMENT CONTACTS

For more information regarding the BEST™ technology, contact Edward Bates, U.S. EPA, Risk Reduction Engineering Laboratory, Cincinnati, Ohio 45268, (513) 569-7774 or FTS 684-7774.

Table 5
BEST™ Status at CERCLA Sites

SELECTED:		
Region 4 - General Refining, GA (Removal Action) FY88-FY87	PCBs, lead in Sludge	3,700 tons

SITE Technology Profile

DEMONSTRATION PROGRAM

CF SYSTEMS CORPORATION
(Solvent Extraction)

TECHNOLOGY DESCRIPTION:

This technology uses liquified gas solvent to extract organics (such as hydrocarbons), oil, and grease from wastewater or contaminated sludges and soils. Carbon dioxide is the gas used for aqueous solutions, while propane and/or butane is used for sediment, sludges and soils (semisolids).

Contaminated solids, slurrys or wastewaters are fed into the extractor (Figure 1). Solvent (gas condensed by compression) is also fed to the extractor, making nonreactive contact with the waste. Typically, more than 99 percent of the organics are separated from the feedwaste. Following phase separation of the solvent and organics, treated water is removed from the extractor while the mixture of solvent and organics passes to the separator through a valve, where pressure is partially reduced. In the separator, the solvent is vaporized and recycled as fresh solvent. The organics are drawn off from the separator, and either reused or diposed.

The extractor design is different for contaminated wastewaters and semisolids. For wastewaters, a tray tower contactor is used. For semisolids, a series of extractor/decanters operating countercurrently is used.

WASTE APPLICABILITY:

This technology can be applied to waste containing carbon tetrachloride, chloroform, benzene, naphthalene, gasoline, vinyl acetate, furfural, butyric acid, higher organic acids, dichloroethane, oils and grease, xylene, toluene, methyl acetate, acetone, higher alcohols, butanol, propanol, phenol, heptane, PCBs and other complex organics.

STATUS:

The pilot-scale system was tested on PCB-laden sediments from the New Bedford (Mass.) Harbor Superfund site during September 1988.

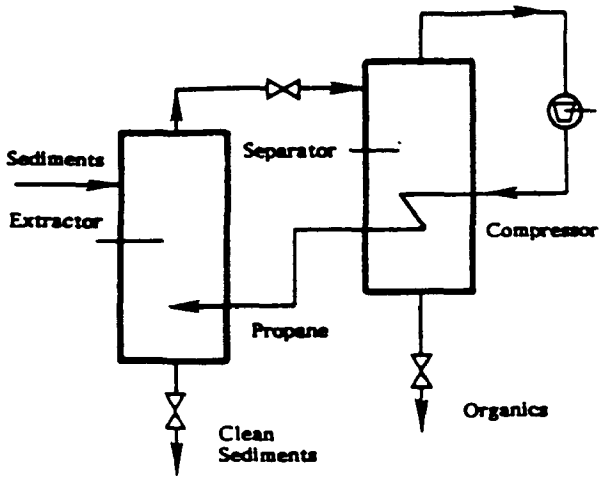


Figure 1. Solvent extraction unit process diagram.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles EPA/540/5-90/006 (1990).

PCB concentrations in the harbor ranged from 300 ppm to 2,500 ppm. The Technology Evaluation Report (TER) was published in early 1990 (EPA/540/5-90/002).

Commercial systems have been sold to Clean Harbors, Braintree, Massachusetts, for wastewater clean-up; and Ensco of Little Rock, Arkansas, for incinerator pretreatment. A unit is in operation at Star Enterprise, Port Arthur, Texas, treating API separator sludge to meet Best Demonstrated and Available Technology (BDAT) standards for organics.

DEMONSTRATION RESULTS:

This technology was demonstrated concurrently with dredging studies managed by the U.S. Army Corps of Engineers. Contaminated sediments were treated by the CF Systems Pit Cleanup Unit, using a liquified propane and butane mixture as the extraction solvent.

The following test results include the number of passes made during each test and the concentration of PCBs before and after each test:

	Passes	PCB concentration	
		Before	After
Test 2	9	360 ppm	8 ppm
Test 3	3	288 ppm	82 ppm
Test 4	6	2575 ppm	200 ppm

Extraction efficiencies were high, despite some operating difficulties during the tests. The use of treated sediment as feed to the next pass caused cross-contamination in the system. Full scale commercial systems are designed to eliminate problems associated with the pilot plant design.

APPLICATIONS ANALYSIS SUMMARY:

The following conclusions were drawn from this series of tests and other data:

- Extraction efficiencies of 90-98% were achieved on sediments containing between 350 and 2,575 ppm PCBs. PCB concentrations were as low as 8 ppm in the treated sediment.
- In the laboratory, extraction efficiencies of 99.9% have been obtained for volatile and semivolatile organics in aqueous and semi-solid wastes.
- Operating problems included solids being retained in the system hardware and foaming in receiving tanks. The vendor identified corrective measures that will be implemented in the full-scale commercial unit.
- Projected costs for PCB cleanups are estimated at approximately $150 to $450 per ton, including material handling and pre- and post-treatment costs. These costs are highly sensitive to the utilization factor and job size, which may result in lower costs for large cleanups.

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DEHYDRO-TECH CORPORATION
(Carver-Greenfield Process for Extraction of Oily Waste)

TECHNOLOGY DESCRIPTION:

The Carver-Greenfield Process® is designed to separate materials into their constituent solid, oil (including oil-soluble substances), and water phases. It is primarily intended for soils and sludges contaminated with oil-soluble hazardous compounds. The technology uses a food-grade "carrier oil" to extract the oil-soluble contaminants (Figure 1). Pretreatment is necessary to achieve particle sizes less than 3/8-inch.

The carrier oil, with a boiling point of 400° F, typically is mixed with waste sludge or soil and the mixture is placed in the evaporation system to remove any water. The oil serves to fluidize the mix and maintain a low slurry viscosity to ensure efficient heat transfer, allowing virtually all of the water to evaporate.

Oil-soluble contaminants are extracted from the waste by the carrier oil. Volatile compounds present in the waste are also stripped in this step and condensed with the carrier oil or water. After the water is evaporated from the mixture, the resulting dried slurry is sent to a centrifuging section that removes most of the carrier oil from the solids.

After centrifuging, residual carrier oil is removed by a process known as "hydroextraction." The carrier oil is recovered by evaporation and steam stripping. The hazardous constituents are removed from the carrier oil by distillation. This stream can be incinerated or reclaimed. In some cases, heavy metals in the solids will be complexed with hydrocarbons and will also be extracted by the carrier oil.

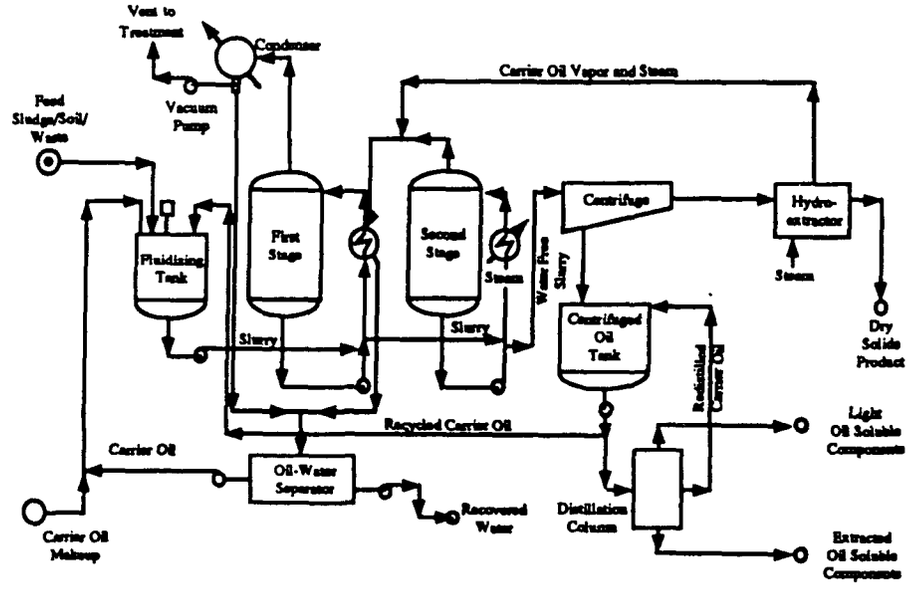

Figure 1. Simplified Carver Greenfield process flow diagram.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

The Carver-Greenfield process can be used to treat sludges, soils, and other water-bearing wastes containing oil-soluble hazardous compounds, including PCBs, PNAs, and dioxins. The process has been commercially applied to municipal wastewater sludge, paper mill sludge, rendering waste, pharmaceutical plant sludge, and many other wastes.

STATUS:

The process has been successfully tested in a pilot plant on refinery "slop oil," consisting of 72 percent water, as well as on a mixed refinery waste consisting of dissolved air flotation sludge, API separator bottoms, tank bottoms, and biological sludge. EPA has identified the PAB Oil site in Louisiana as a potential site for demonstrating this technology. The PAB oil site contains petroleum wastes and contaminated soils, and a SITE demonstration is tentatively planned for January 1991.

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SITE Technology Profile

DEMONSTRATION PROGRAM

SANIVAN GROUP
(Soil Treatment with Extraksol)

TECHNOLOGY DESCRIPTION:

Extraksol is a mobile solvent extraction technology. This batch process extracts organic contaminants from the soil using nonchlorinated, non-persistent organic solvents. The solvents are regenerated by distillation and the contaminants are concentrated in the distillation residues.

The three treatment steps -- soil washing, soil drying, and solvent regeneration -- occur on a flatbed trailer. The extraction fluid (solvent) is circulated through the contaminated matrix within a tumbling vat to wash the soil. Controlled temperature and pressure optimize the washing procedure. Hot inert gas dries the soil.

The gas vaporizes the residual extract fluid and carries it from the tumbling vat to a condenser, where the solvent is again separated from the gas. The now solvent-free gas is reheated and reinjected into the soil as required for complete drying. After the drying cycle, the decontaminated soil may be returned to its original location.

Distillation of the contaminated solvent achieves two major objectives: (1) it minimizes the amount of solvent required to perform the extraction by regenerating it in a closed loop, and (2) it significantly reduces the volume of contaminants requiring further treatment or off-site disposal by concentrating them in the still bottoms. A schematic of the process is shown in Figure 1.

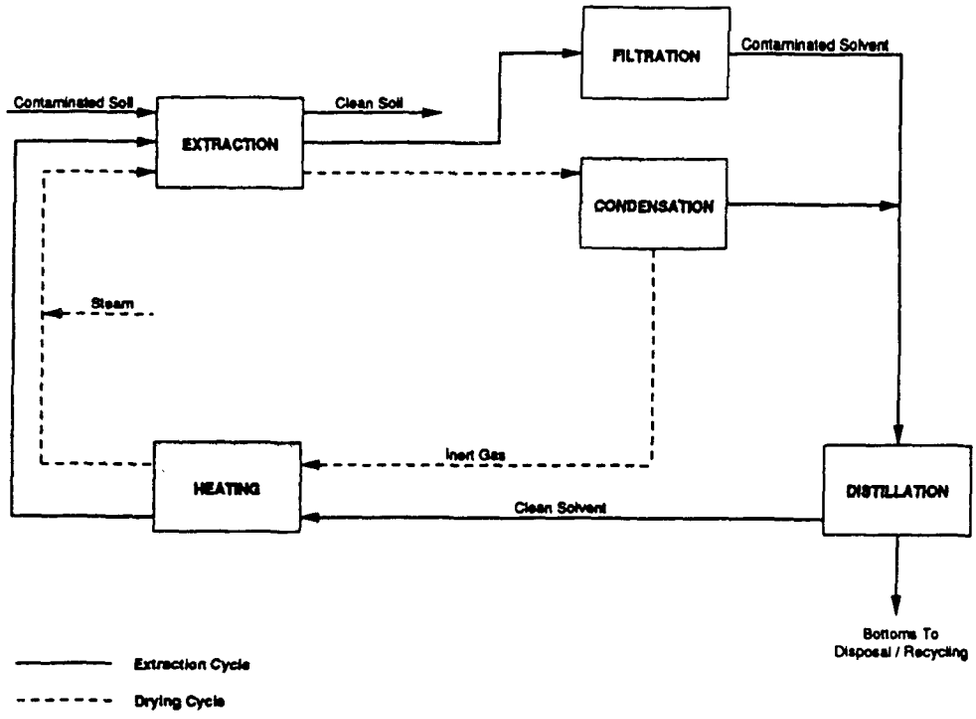

Figure 1. Simplified Schematic of Extraksol ™ Process

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

The process extracts organic contaminants from solids. It has been successfully tested in a number of pilot projects on a range of contaminants, including PCBs, PCP, PAH, MAH, pesticides, oils, and hydrocarbons. The process has the following soil restrictions:

- Maximum clay fraction, 40%
- Maximum water content, 30%
- Maximum size if porous material, 2 inches
- Maximum size if non-porous material, 1-2 feet

STATUS:

This technology was accepted into the SITE program in June 1990.

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Superfund | September 1990

Engineering Bulletin

EPA Solvent Extraction Treatment

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants and contaminants as a principal element." The Treatment Technology Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial investigation scoping needs. Addenda will be issued periodically to update the original bulletins.

Abstract

Solvent extraction does not destroy wastes, but is a means of separating hazardous contaminants from soils, sludges, and sediments, thereby reducing the volume of the hazardous waste that must be treated. Generally it is used as one in a series of unit operations, and can reduce the overall cost for managing a particular site. It is applicable to organic wastes and is generally not used for treating inorganics and metals [15, p.64].* The technology uses an organic chemical as a solvent [14, p. 30], and differs from soil washing, which generally uses water or water with wash improving additives. During 1989, the technology was one of the selected remedies at six Superfund sites. Commercial-scale units are in operation. There is no clear solvent extraction technology leader by virtue of the solvent employed, type of equipment used, or mode of operation. The final determination of the lowest cost alternative will be more site specific than process equipment dominated. Vendors should be contacted to determine the availability of a unit for a particular site. This bulletin provides information on the technology applicability, the types of residuals produced, the latest performance data, site requirements, the status of the technology, and sources for further information.

Technology Applicability

Solvent extraction has been shown to be effective in treating sediments, sludges, and soils containing primarily organic contaminants such as polychlorinated biphenyls (PCB), volatile organic compounds (VOC), halogenated solvents, and petroleum wastes. The technology is generally not used for extracting inorganics (i.e., acids, bases, salts, heavy metals). Inorganics usually do not have a detrimental effect on the extraction of the organic components, and sometimes metals that pass through the process experience a beneficial effect by changing the chemical compound to a less toxic or leachable form. The process has been shown to be applicable for the separation of the organic contaminants in paint wastes, synthetic rubber process wastes, coal tar wastes, drilling muds, wood treating wastes, separation sludges, pesticide/insecticide wastes, and petroleum refinery oily wastes [3].

Table 1 lists the codes for the specific Resource Conservation and Recovery Act (RCRA) wastes that have been treated by this technology [3][1, p.11]. The effectiveness of solvent extraction on general contaminant groups for various matrices is shown in Table 2 [13, p.1] [15, p.10]. Examples of constituents within contaminant groups are provided in Reference 16, "Technology Screening Guide for Treatment of CERCLA Soils and Sludges." This table is based on the current available information or professional judgment where no information was available. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the treatment efficiencies achieved will be acceptable at other sites. For the ratings used for this table, demonstrated effectiveness means that, at some scale treatability was tested to show the technology was effective for that particular contaminant and matrix. The ratings of potential effectiveness, or no expected effectiveness are both based upon expert judgment. Where potential effectiveness is indicated, the technology is believed capable of successfully treating the contaminant group in a particular matrix. When the technology is not applicable or will probably not work for a particular combination of contaminant group and matrix, a no-expected-

* [reference number, page number]

effectiveness rating is given. Another source of general observations and average removal efficiencies for different treatability groups is contained in the Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions," (OSWER Directive 9347.3-06FS) [17] and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-07FS) [18].

Table 1
RCRA Codes for Wastes Treated by Solvent Extraction

Wood Treating Wastes	K001
Water Treatment Sludges	K044
Dissolved Air Flotation (DAF) Float	K048
Slop Oil Emulsion Solids	K049
Heat Exchanger Bundles Cleaning Sludge	K050
American Petroleum Institute (API) Separator Sludge	K051
Tank Bottoms (leaded)	K052
Ammonia Still Sludge	K060
Pharmaceutical Sludge	K084
Decanter Tar Sludge	K089
Distillation Residues	K101

Table 2
Effectiveness of Solvent Extraction on General Contaminant Groups for Soil, Sludge, and Sediments

	Treatability Groups	Effectiveness Soil	Sludge	Sediments
Organic	Halogenated volatiles	▼	▼	▼
	Halogenated semivolatiles	■	▼	▼
	Nonhalogenated volatiles	■	■	▼
	Nonhalogenated semivolatiles	■	■	▼
	PCBs	■	■	■
	Pesticides	■	▼	▼
	Dioxins/Furans	▼	▼	▼
	Organic cyanides	▼	▼	▼
	Organic corrosives	▼	▼	▼
Inorganic	Volatile metals	□	□	□
	Nonvolatile metals	□	□	□
	Asbestos	□	□	□
	Radioactive materials	□	□	□
	Inorganic corrosives	□	□	□
	Inorganic cyanides	□	□	□
Reactive	Oxidizers	□	□	□
	Reducers	□	□	□

■ Demonstrated Effectiveness: Successful treatability test at some scale completed
▼ Potential Effectiveness: Expert opinion that technology will work
□ No Expected Effectiveness: Expert opinion that technology will not work

Limitations

Organically bound metals can co-extract with the target organic pollutants and become a constituent of the concentrated organic waste stream. This is an unfavorable occurrence because the presence of metals can restrict both disposal and recycle options.

The presence of detergents and emulsifiers can unfavorably influence extraction performance and materials throughput. Water-soluble detergents, found in some raw wastes (particularly municipal), will dissolve and retain organic pollutants in competition with the extraction solvent. This can impede a system's ability to achieve low concentration treatment levels. Detergents and emulsifiers can promote the evolution of foam, which hinders separation and settling characteristics and generally decreases materials throughput. Although methods exist to combat these problems, they will add to the process cost.

When treated solids leave the extraction subsystem, traces of extraction solvent will be present [8]. The typical extraction solvents used in currently available systems either volatilize quickly from the treated solids or biodegrade easily. Ambient air monitoring can be employed to determine if the volatilizing solvents present a problem.

The types of organic pollutants that can be extracted successfully depends, in part, on the nature of the extraction solvent. Invariably, treatability tests should be conducted to determine which solvent or combination of solvents is best suited to the site-specific vagaries of a particular parameter/matrix mix. In general, solvent extraction is least effective on very high molecular weight organics and very hydrophilic substances.

Some commercially available extraction systems use solvents that are either flammable or mildly toxic or both [20, p. 2]. However, there are long-standing standard procedures used by chemical companies, gasoline stations, etc., that can be used to greatly reduce the potential for accidents.

Technology Description

Figure 1 is a general schematic of the solvent extraction process [3][15, p. 65][4, p. 3].

Waste preparation (1) includes excavation and/or moving the waste material to the process where it is normally screened to remove debris and large objects. Depending upon the process vendor and whether the process is semibatch or continuous, the waste may need to be made pumpable by the addition of solvent or water.

In the extractor (2), the waste and solvent mix, resulting in the organic contaminant dissolving into the solvent. The extraction behavior exhibited by this technology is typical of a mass transfer controlled process, although equilibrium considerations often become limiting factors. It is important to

have a competent source conduct a laboratory-scale treatability test to determine whether mass transfer or equilibrium will be controlling. The controlling factor is critical to the design of the unit and to the determination of whether the technology is appropriate for the waste.

The extracted organics are removed from the extractor with the solvent and go to the separator (3), where the pressure or temperature is changed, causing the organic contaminants to separate from the solvent [9, p. 4-2].

The solvent is recycled (4) to the extractor and the concentrated contaminants (5) are removed from the separator [11, p. 6].

Process Residuals

There are three main product streams generated by this technology: the concentrated contaminants, the treated soil or sludge, and the separated water. The extract contains solvent-free contaminants, concentrated into a smaller volume, for post treatment. The recovered contaminants may require analysis to determine their suitability for recycle, reuse, or further treatment before disposal.

The cleaned soil and solids from treated sludge or sediments may need to be dewatered, forming a dry solid and a separate water stream. The volume of product water depends on the inherent dewatering capability of the individual process, as well as the process-specific requirements for feed slurrying. Since the solvent is an organic material, some residue may remain in the soil matrix. This can be mitigated by solvent selection, and if necessary, an additional separation stage. Depending on the extent of metal or other inorganic contaminants, treatment of the cleaned solids by some other technique (i.e., stabilization) may be necessary. Since the organic component has been separated, additional solids treatment should be simplified. The water produced should be analyzed to determine if treatment is necessary before discharge.

Solvent extraction units are designed to operate without air emissions. However, volatile air emissions could occur during waste preparation.

Site Requirements

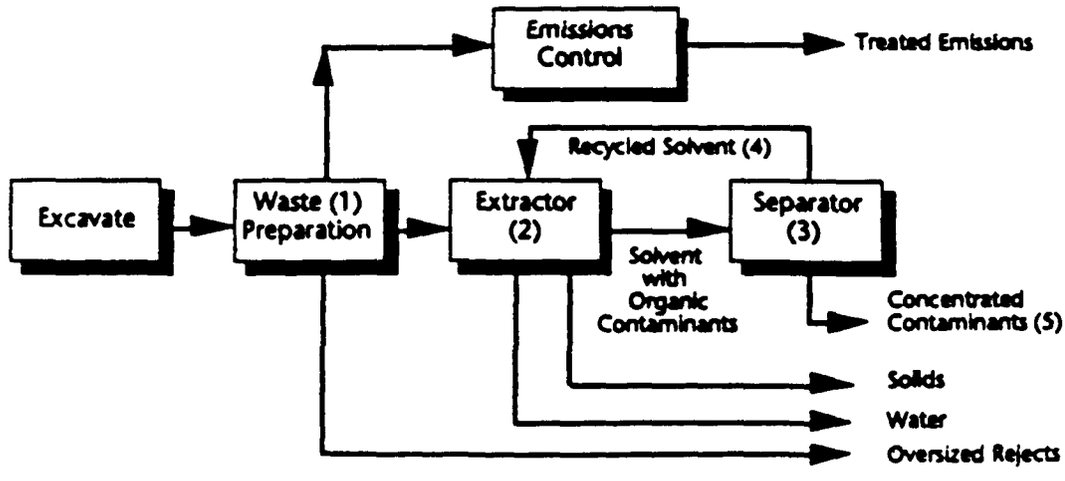
Solvent extraction units are transported by trailers. Therefore, adequate access roads are required to get the unit to the site. Typical commercial-scale units, 50-70 tons per day (tpd), require a setup area of up to 3,600 square feet.

Standard 440V three-phase electrical service is needed. Water must be available at the site [3]. The quantity of water needed is vendor and site specific.

Contaminated soils or other waste materials are hazardous and their handling requires that a site safety plan be developed to provide for personnel protection and special handling measures. Storage should be provided to hold the process product streams until they have been tested to determine their acceptability for disposal or release. Depending upon the site, a method to store waste that has been prepared for treatment may be necessary. Storage capacity will depend on waste volume.

Onsite analytical equipment for conducting oil and grease analyses and a gas chromatograph capable of determining site-specific organic compounds for performance assessment make the operation more efficient and provide better information for process control.

Figure 1. Solvent Extraction Process



Performance Data

The performance data currently available are mostly from two vendors, CF Systems and Resource Conservation Company (RCC).

CF Systems' full-scale 50-tpd commercial unit (PCU 200), which is treating refinery sludge at Port Arthur, Texas, meets or exceeds the EPA's Best Demonstrated Available Technology (BDAT) standards for a number of organic contaminants (Table 3) [3].

Table 3
API Separator Sludge Results*
(Concentrations in mg/kg)

	Feed Concentrations	*BDAT Target*	*Treated Products for Land Disposal*
Benzene	30.2	9.5	0.18
Toluene	16.6	9.5	0.18
Ethylbenzene	30.4	67.0	0.23
Xylenes (Total)	13.2	Reserved	0.98
Anthracene	28.3	6.2	0.12
Benzo(a)anthracene	BMDL**	1.4	0.18
Benzo(a)pyrene	1.9	0.84	0.33
Bis-(2-ethylhexy)phthalate	4.1	37.0	1.04
Chrysene	6.3	2.2	0.69
Di-n-butyl phthalate	BMDL	4.2	0.11
Naphthalene	42.2	Reserved	0.66
Phenanthrene	28.6	7.7	1.01
Phenol	BMDL	2.7	BMDL
Pyrene	7.7	2.0	1.08

* This information is from vendor-published literature; therefore, quality assurance has not been evaluated.
** Below Minimum Detection Limits (different values in Feed and Treated products).

Source: [3], CF Systems, 50 tpd

Under the Superfund Innovative Technology Evaluation (SITE) program, as shown in Table 4, CF Systems demonstrated an overall PCB reduction of more than 90% for harbor sediments with inlet concentrations up to 2,575 ppm [11, p. 6].

A mobile demonstration unit processed different feed types including clay pit material, ditch skimmer sludge, and drainage basin soil. The wastes were contaminated with oil and grease and aromatic priority pollutants. The oil and grease were separated and their concentrations were reduced to between 89% and 94% of the original amount. For the most part, the aromatic compounds were reduced to nondetectable levels [6, p. 10].

A treatability study completed at the Conroe, Texas, Superfund site with the mobile demonstration unit showed that polynuclear aromatic hydrocarbon (PAH) concentrations in the soil were reduced 95% from 2,879 ppm to 122 ppm [12, p. 3-12].

The only available data for the on-line operational availability were from CF Systems, which they estimated to be 85% (corresponding to a treatment process downtime of 15%). This can be verified and possibly improved with increased operating experience.

The ability of RCC's full-scale B.E.S.T.™ process to separate oily feedstock into product fractions was evaluated by the EPA at the General Refining Superfund site near Savannah, Georgia, in February 1987. It is an abandoned waste oil re-refining facility that contained four acidic oily sludge ponds with high levels of heavy metals (Pb=200-10,000 ppm, Cu=83-190 ppm) and detectable PCBs (2.9-5 ppm). The average composition of the sludge from the four lagoons was 10% oil, 20% solids, and 70% water by weight [16, p. 13]. The transportable 70 tons/day B.E.S.T.™ unit processed approximately 3,700 tons of sludge at the General Refining Site. The treated solids from this unit were back filled to the site, product oil was recycled as a fuel oil blend, and the recovered water was pH adjusted and transported to a local industrial wastewater treatment facility.

Test results (Table 5) showed that the heavy metals were mostly concentrated in the solids product fraction. TCLP test results showed heavy metals to be in stable forms that resisted leaching, illustrating a potential beneficial side effect when metals are treated by the process [1, p. 13].

Table 4
New Bedford Harbor Sediments Results
(Concentrations in ppm)

Test #	*Initial PCB Concentration*	*Final PCB Concentration*	*Percent Reduction*	*Number of Passes Through Extractor*
1	350	8	98	9
2	288	47	84	1
3	2,575	200	92	6

Source: [11], CF Systems, 1.5 gpm

Table 5
EPA Data from the General Refining Superfund Site, Savannah, GA

Metals	*Initial Concentration (mg/kg)*	*Product Solids Metal (ppm)*	*TCLP Levels (ppm)*
As	<0.6	<5.0	<0.0
Ba	239	410	<0.03
Cr	6.2	21	<0.05
Pb	3,200	23,000	5.2
Se	<4.0	<5.0	0.008

Source: [1], RCC, 100 tpd

RCC has bench-scale treatability data on a variety of wastes, including steel mill wastewater treatment sludge and oil refinery sludge (Table 6) [1, p. 12], that will illustrate the degree of separation possible among the oil, water, and solids components of the waste. The separation of PCBs in contaminated harbor sediments is shown in Table 7 and in a variety of matrices in Table 8. Results of treatment of pesticide-contaminated soils are shown in Table 9.

RCRA Land Disposal Restrictions (LDRs) that require treatment of wastes to BDAT levels prior to land disposal may sometimes be determined to be applicable or relevant and appropriate requirements (ARARs) for CERCLA response actions. The solvent extraction technology can produce a treated waste that meets treatment levels set by BDAT, but may not reach these treatment levels in all cases. The ability to meet required treatment levels is dependent upon the specific waste constituents and the waste matrix. In cases where solvent extraction does not meet these levels, it still may, in certain situations, be selected for use at the site if a treatability variance establishing alternative treatment levels is obtained. EPA has made the treatability variance process available in order to ensure that LDRs do not unnecessarily restrict the use of alternative and innovative treatment technologies. Treatability variances may be justified for handling complex soil and debris matrices. The following guides describe when and how to seek a treatability variance for soil and debris: Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions" (OSWER Directive 9347.3-06FS) [17], and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-07FS) [18]. Another approach could be to use other treatment techniques in series with solvent extraction to obtain desired treatment levels.

Table 6
Oil and Grease Removal
Bench Scale

	Steel Mill Sludge	*Refinery Sludge*
Original Sludge		
Concentration		
Oil %	11	8
Water %	33	77
Solids %	56	15
Product Stream		
Oil		
Water %	<2	<1
Solvent (ppm)	<100	<150
Water		
Oil & Grease (ppm)	<100	<100
Solvent (ppm)	11	12
Solid		
Oil & Grease (ppm)	0.2	0.9
Solvent (ppm)	34	N/A

Source: RCC, 6 kg Batch

Table 7
Harbor Sediments
PCB Extraction — Bench Scale

Original Sediments	4,500 ppm
Product Stream	
Oil	75,000 ppm
Water	10 ppb
Solid	<1 ppm
% Removal	>99%

Source: RCC, 6 kg Batch

Technology Status

During 1989, solvent extraction technology was selected as the remedial action to clean up 2,000-2,200 cubic yards of soil contaminated with PCBs and organics at the Pinette Salvage Superfund site in Washburn, Maine [13, p. 2]. In 1989, solvent extraction was also selected as the source control remedy in the following Records of Decision: F. O'Connor Superfund site in Augusta, Maine; the Norwood PCBs Superfund site in Norwood, Massachusetts; the Ewan Property Superfund site in Shamong, New Jersey; United Creosoting in Conroe, Texas; and Outboard Marine, State of Illinois [19].

The most significant factors influencing costs are the waste volume, the number of extraction stages, and the operating parameters such as labor, maintenance, setup, decontamination, demobilization, and lost time resulting from equipment operating delays. Extraction efficiency can be influenced by process parameters such as solvent used, solvent/waste ratio, throughput rate, extractor residence time, and number of extraction stages. Thus, variation of these parameters in a particular hardware design and/or configuration will influence the treatment unit cost component, but should not be a significant contributor to the overall site costs.

Cost estimates for this technology range from $100 to $500 per ton.

Solvent Extraction Systems

Solvent extraction systems are at various stages of development. The following is a brief discussion of six systems that have been identified.

CF Systems uses liquefied hydrocarbon gases such as propane and butane as solvents for separating organic contaminants from soils, sludges, and sediments. The extraction units are liquid-filled systems that employ pumps to move the material through the system. As such, the feed material is pretreated, through the addition of water, to ensure the "pumpability" of the material [10, p. 12]. The pH of the feed

Table 8
PCB Samples Tested in RCC's Laboratory (1/87 through 7/88)

Client	As Received	Raw Sample Phase Composition			PCBs in Product Fraction			
	PCB (mg/kg)	Oil %	Water %	Solids %	Oil (mg/kg)	Water (mg/kg)	Solids (mg/kg)	% Removal
SLUDGES								
GRI	5.9	27	66	7	9.3	<.005	<.01	99.9%
GRI	4.7	10	58	32	N/A	<.01	0.015	99.9%
GRI	5.3	13	57	30	N/A	<.01	0.14	99.2%
Superfund Site Sh	106	35	44	21	270	N/A	1.0	99.8%
Superfund Site CO "A"	51	49	28	23	80	N/A	0.44	99.8%
Superfund Site CO "B"	21	23	24	53	71	N/A	0.08	99.8%
Superfund Site CO "C"	11	15	16	69	52	N/A	0.06	99.6%
SEDIMENTS								
River Sediment "B"	960	26	17	83	N/A	N/A	40	96.5%
Superfund B (#13)	83	44	40	16	N/A	N/A	1.0	99.8%
Harbor Sediment "B"	20,000	3	22	75	970,000	<.006	27	99.9%
Harbor Sediment "C"	30,000	5.6	62	32	550,000	N/A	94	99.9%
Harbor Sediment "D"	430	0.38	47	53	N/A	N/A	32	96.0%
Harbor Sediment NB-A	5,800	1.9	69	29	280,000	<.005	35	99.4%
Harbor Sediment NB-B	16,500	4.3	51.6	44.1	360,000	<.005	75	99.8%
SOILS								
Industrial Soil A	250	0.06	9.4	91	120,000	N/A	2.2	99.1%
Industrial Soil B	120	0.06	13	87	280,000	N/A	6.4	94.7%
Industrial Soil D	5,300	1.0	19	80	370,000	N/A	11	99.8%
Industrial Soil J	19	.09	16	84	10,000	N/A	0.7	96.3%

Source: RCC, .6 kg Batch

may be adjusted, through the addition of lime or a similar material, to maintain the metallurgical integrity of the system. Typically, the feed material is screened to remove particles of greater than 1/8" diameter. Depending upon the nature of the oversize material, the large particles may be reduced in size and then returned to the extraction unit for processing.

CF Systems' extraction technology has been demonstrated in the field at two Superfund sites and approximately 10 refineries and treatment, storage, and disposal (TSD) facilities to date.

CF Systems' solvent extraction technology is available in several commercial sizes and the Mobile Demonstration Unit is available for onsite treatability studies. To date, CF Systems has supplied three commercial-scale extraction units for the treatment of a variety of wastes [12, p. 3-12]. A 60-tpd treatment system was designed to extract organic liquids from a broad range of hazardous waste feeds at ENSCO's El Dorado, Arkansas, incinerator facility. A commercial-scale extraction unit is being installed at a facility in Baltimore, Maryland, to remove organic contaminants from a 20-gpm wastewater stream. A PCU-200 extraction unit is installed and operating at the Star Enterprise (Texaco) refinery in Port Arthur, Texas. This unit is designed to treat listed refinery wastes to meet or exceed the EPA's BDAT standards. Performance data and the technology status are explained in the body of this bulletin.

RCC's B.E.S.T.™ system uses aliphatic amines (typically triethylamine) as the solvent to separate and recover contaminants [1, p. 2]. It is applicable to soils, sludges, and sediments, and in batch mode of operation does not need a pumpable waste. Before the extraction process is begun, feed materials are screened to remove particles of greater than 1" diameter and pH adjusted to an alkaline condition. The process operates at or near ambient temperature and pressure. Triethylamine can be recycled from the recovered liquid phases via steam stripping because of its high vapor pressure and low boiling point azeotrope formation.

RCC has a transportable B.E.S.T.™ pilot-scale unit available to treat soils and sludges. This pilot-scale equipment has been used at a gulf coast refinery treating various refinery waste streams and has treated PCB-contaminated soils at an industrial site in Ohio in November 1989. A full-scale unit with a nominal capacity of 70 tpd was used to clean up 3,700 tons of PCB-

contaminated petroleum sludge at the General Refining Superfund Site in Savannah, Georgia, in 1987. Performance data and the technology status are explained in the body of this bulletin.

ENSR is in the process of developing a mobile solvent extraction unit capable of decontaminating soils and sludges at a rate of 5 to 10 cubic yards/hour [5, p. 1]. The ENSR system uses a proprietary reagent and solvent. The company claims that its solvent extraction system is designed to operate without significant pretreatment of the soil/sludge and without the addition or removal of water. Design of a pilot-scale unit is near completion. Thus far, only performance data from earlier bench-scale tests are available.

The Extraksol™ process was developed in 1984 by Sanivan Group, Montreal, Canada [7, p. 35]. It is applicable to soils, sludges, and sediments. Performance data on contaminated soils and refinery wastes are available for a 1 ton per hour (tph) mobile unit. The process uses a proprietary solvent that reportedly achieved removal efficiencies up to 99% (depending on the number of extraction cycles and the type of soil) on PCBs, oil, grease, PAHs, and pentachlorophenol [1, p. 45]. The 1-tph unit is suitable for small projects with a maximum of 300 tons of material to be treated. The Sanivan group is planning to build a full-scale unit that can process 6-8 tph of waste [7, p. 41].

Harmon Environmental Services and Acurex Corporation are involved in a cooperative joint venture to develop a solvent soil washer/extraction system appropriate for the onsite remediation of Superfund and RCRA sites. They have completed EPA-sponsored bench-scale studies on different types of soils contaminated with #2 fuel oil. The design of a pilot plant unit is being considered.

The Low Energy Extraction Process (LEEP) is a patented solvent extraction process that can be used onsite for decontaminating soils, sludges, and sediments. LEEP uses common hydrophilic and hydrophobic organic solvents to extract and further concentrate organic pollutants such as PCBs [2, p. 3]. Bench-scale studies are available. The design of the pilot plant is completed, and the plant is scheduled for operation at the beginning of 1990.

EPA Contact

Technology-specific questions regarding solvent extraction may be directed to:

Michael Gruenfeld
U.S. EPA, Risk Reduction Engineering Laboratory
GSA Raritan Depot
Woodbridge Avenue
Edison, New Jersey 08837
FTS 340-6625
(201) 321-6625

Table 9
RCC B.E.S.T.™ Treated Pesticide-Contaminated Soil — Bench Scale

Analyte	Feedstock (ppm)	Product Solids (ppm)	Removal Efficiency %
p,p'-DDT	500	0.2	99.96
p,p'-DDE	84	0.5	99.4
p,p'-DDD	190	0.05	99.97
Endosulfan-I	250	<0.02	>99.99
Endosulfan-II	140	<0.02	>99.99
Endrin	140	0.02	99.99
Dieldrin	37	<0.02	>99.95
Toxaphene	2,600	0.9	99.97
BHC-Beta	<30	<0.13	-
BHC-Gamma (Lindane)	<30	<0.07	-
Pentachlorophenol	150	1.9	98.7

Source: RCC, .6 kg Batch

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5.15 KEY REFERENCE LIST - SOLVENT EXTRACTION

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Note: A more comprehensive bibliography is being developed.

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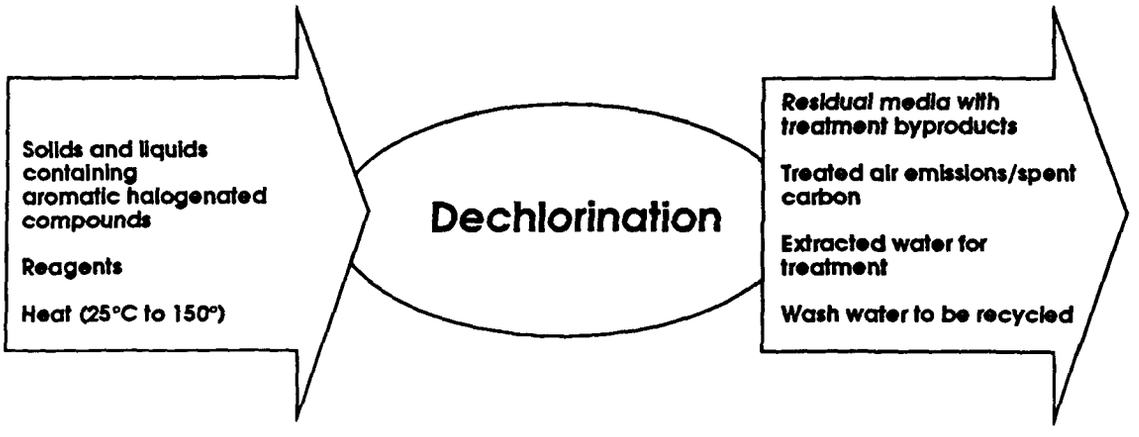
6.0 DECHLORINATION

6.1 TECHNOLOGY DESCRIPTION

The Alkaline Metal Hydroxide/Polyethylene Glycol (APEG) dehalogenation technology uses a glycolate reagent generated from an alkaline metal hydroxide and a glycol to remove halogens (e.g., chlorine, bromine, fluorine, etc.) from halogenated aromatic organic compounds in a batch reactor. KPEG (potassium hydroxide/polyethylene glycol) is the most commonly used type of APEG reagent. Potassium hydroxide, or sodium hydroxide/tetra-ethylene glycol (ATEG), is another variation of the reagent. APEG processes involve heating and physical mixing of contaminated soils, sludges, or liquids with the chemical reagents. During the reaction, water vapor and volatile organics are removed and condensed. Carbon filters are used to trap volatile organic compounds that are not condensed in the vapor. The treated residue is rinsed to remove reactor by products and reagent and then dewatered before disposal. The process results in treated soil and wash water.



• Batch process

6.2 TECHNOLOGY STATUS

- Dechlorination was selected by EPA for cleanup at five Superfund remedial sites: Wide Beach, New York; Resolve, Massachusetts; Sol Lynn, Texas; Myers Property, New Jersey; and Tenth Street Dump, Oklahoma. None of these cleanups has been completed. It was also selected for three emergency response actions.
- The Wide Beach cleanup is ongoing. The process is a combination of APEG and the AOSTRA - Taciuk process. A project case study is included as Exhibit 4.
- The technology has been approved by EPA's Office of Toxic Substances to treat PCBs under the Toxic Substances Control Act.

6.3 APPLICATIONS

- Dechlorination reduces the toxicity of halogenated organic compounds - particularly dioxin and furans, PCBs, and certain chlorinated pesticides.
- It is appropriate for soils, sludges, sediments, and liquids.

6.4 TECHNOLOGY STRENGTHS

- It has greater public acceptance than incineration.
- Dehalogenation has been used successfully to treat contaminant concentrations of PCBs reported as high as 45,000 ppm to less than 2 ppm.
- Uses standard reactor equipment to mix/heat soil and reagents.
- Energy requirements are moderate, and operation and maintenance costs are relatively low.

6.5 TECHNOLOGY LIMITATIONS

- Most effective with aromatic halides when APEG and KPEG reagents are used, although ATEG reportedly works with aliphatic halides. The presence of other pollutants, such as metals and other inorganics, can interfere with the process.
- Wastewater will be generated from the residual washing process. Treatment may include chemical oxidation, biodegradation, carbon adsorption, or precipitation.
- Engineering controls, such as a lined and bermed treatment area and carbon filters on gas effluent stacks, may be necessary to guard against releases to the environment.

6.6 POTENTIAL MATERIALS HANDLING REQUIREMENTS

- Excavation is required.
- The waste material must be screened to remove debris and large particles
- Size reduction techniques can be used to achieve a feed size required by the equipment.
- The pH of the waste may require adjustment. The KPEG process operates under highly alkaline conditions. The pH of acidic material must be adjusted to provide an alkaline environment.
- The waste may require dewatering. Very wet (less than 20 percent water) material requires excessive quantities of reagent.
- The temperature of the wastes may be adjusted.
  - The KPEG process operates at 212°F - 350°F. Waste material must be heated.
- The waste material and reagent may be mixed to ensure adequate transfer of the contaminants.

6.7 WASTE CHARACTERISTICS AFFECTING PERFORMANCE

- Treatability studies are necessary to help determine the residence time in the reactor. The treatment process is affected by the type of contaminant; initial and desired final concentrations; pH; water content; humic and clay content of soils.
- The ability to recover and recycle reagents is key to determining process cost effectiveness.
- Although individual batch units may have limited capacity, several may be operated in parallel for a large-scale remediation.

6.8 BASE-CATALYZED DECOMPOSITION (BCD)

BCD is another technology for removing chlorine molecules from contaminants such as PCBs, dioxins, and pentachlorophenols. The EPA and the U.S. Navy are conducting extensive research on this new technology. Like the KPEG process, BCD requires the addition of a reagent to the contaminated soils and heating of the material for the reaction. But because the reagent is not a glycol reagent, it is significantly less expensive than the KPEG reagent.

Laboratory research indicates that the BCD process is appropriate for PCBs, pentachlorophenol, dioxins, and chlorinated pesticides with a very high destruction/removal rate.

It also appears to work well on all types of soils. Because this technology has not been widely applied, it is difficult to predict what difficulties will arise at future sites. To be effective, it requires the soil to be screened or ground. In 1991, the U.S. Navy will be applying BCD at a site in Guam. This technology is discussed in greater detail in Exhibit 5.

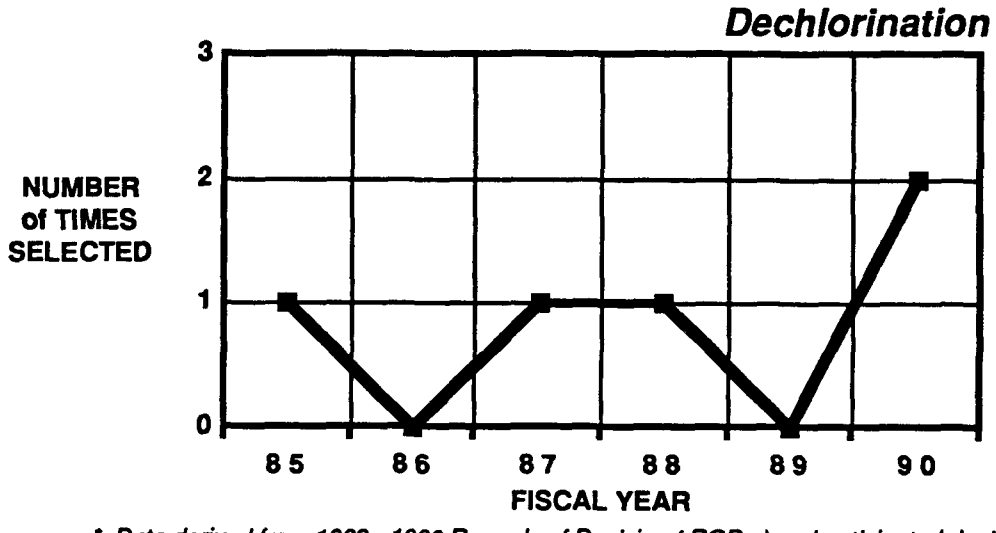
6.9 EXHIBIT 1 - WASTE CHARACTERISTIC TABLE

Waste Type: Soils and Sludges
Technology: Glycolate Dechlorination

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Elevated concentrations of chlorinated organics	Concentrations greater than 5% require excessive volumes of reagent. (Low ppm is optimum.)	Analysis for priority pollutants
Presence of: • Aliphatic organics • Inorganics • Metals	Reagent effective only with aromatic halides (PCBs, dioxins, chlorophenols, chlorobenzenes).	Analysis for priority pollutants
High moisture content (>20%)	Water may require excessive volumes of reagent	Soil moisture content
Low pH (<2)	Process operates under highly alkaline conditions.	pH testing
Presence of other alkaline reactive	Aluminum and possibly other metals that react under highly alkaline conditions may increase amount of reagent required by competing for the KPEG. The reaction may also produce hydrogen gas.	Metals analysis
High humic content in soil	Increases reaction time. Clay and sandy soils as well as high organic content soils can be treated with increased reaction time.	Organic content in soil

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

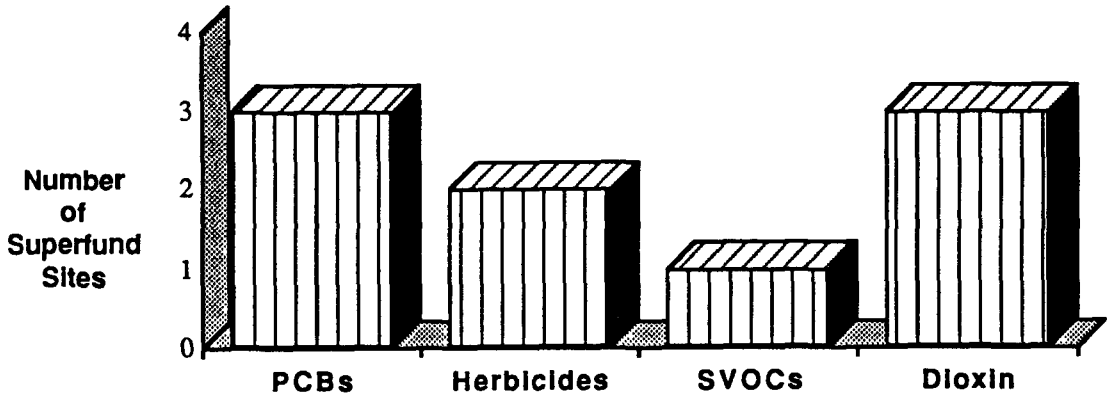
Selection Frequency*



* *Data derived from 1982 - 1990 Records of Decision (RODs) and anticipated design and construction activities.*

September 1991

Contaminants Treated By Dechlorination



* *Data derived from 1982 – 1990 Records of Decision (RODs) and anticipated design and construction activities. At some sites, the treatment is for more than one major contaminant.*

EXHIBIT 3 - INNOVATIVE TREATMENT TECHNOLOGIES: SEMI-ANNUAL STATUS REPORT

Dechlorination

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
1	Re-Solve, MA* (09/24/87) Also see Thermal Desorption	Dechlorination of Residuals from Thermal Desorption	Chemical Reclamation Facility	Residuals from Thermal Desorption of 22,500 cy of Soil	PCBs	Design completion planned 1993	PRP Lead/ Mixed Funding; Chemical Waste Management, Inc.	Lorenzo Thanto 617-223-5500 FTS 883-1500
2	Myers Property, NJ* (09/28/90) Also see Soil Washing	Dechlorination (followed by soil washing)	Pesticide Manufacturing	Soil and Sediments (50,000 cy combined)	SVOCs (Hexachloro-benzene), DDT, Dioxin, TCDD, DDD, and DDE	Predesign	Fund lead/In Negotiation	John Prince 212-264-1213 FTS 264-1213
2	Signo Trading/Mt. Vernon, NY (Emergency Response -AM signed 12/19/86)	KPEG Treatment	Waste management facility (warehouse)	Sludge (15 gals)	Dioxin (2,3,7,8 TCDD-laden herbicides)	Project completed; Operational 10/20/87 - 10/21/87	Fund Lead; Galson Research Corp. (subcontractor to OHM)	Charles Fitzsimmons 201-321-6608 FTS 340-6608
2	Wide Beach Development, NY* (09/30/85)	APEG dechlorination using anaerobic thermal process unit	Contaminated Road Dust, Driveways, and Ditches	Soil (22,000 cy)	PCBs	Project complete; Operational 10/90 - 6/91	Fund Lead/USACE; SoilTech, Inc. (subcontractor to Kimmins)	Herb King 212-264-1129 FTS 264-1129
6	Fruitland Drum, NM (Emergency Response -AM signed 9/8/90)	Dechlorination	Operation and maintenance facility	Liquid (150 gals/bench scale)	Dioxins (2,4,5,T)	Treatability study for APEG/KPEG was unsuccessful; EPA considering BCD	Fund Lead; Galson Research Corp.	Craig Carlton 214-655-2270 FTS 255-2270
6	Sol Lynn/Industrial Transformers, TX* (03/25/88)	APEG - Plus Dechlorination	Transformer and Solvent Recycler	Soil (800 cy); Oil (400 gals)	PCBs	Installation scheduled to begin Fall '91	PRP Lead; Galson Research Corp. (subcontractor to ENSR Consulting)	John Meyer 214-655-6735 FTS 255-6735
6	Tenth Street Dump/Junkyard, OK* (09/27/90)	Dechlorination	Salvage yard and industrial waste dump	Soil (7,500 cy)	PCBs	In design; Design completion planned Spring '92	Fund Lead	Noel Bennett 214-655-6715 FTS 655-6715
7	Crown Plating, MO (Emergency Response -AM signed 8/29/89)	KPEG Treatment	Electroplating facility	Liquid (55 gals)	Herbicide (silvex; 2,4,5 TP)	Project completed in 1989	Fund Lead	Mark Roberts 913-236-3881 FTS 757-3881

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Wide Beach Development Site -- Case Study

Jack D. Generaux
US Army Corps of Engineers, Kansas City District

I. Site History and Description

A. Location and Setting

The Wide Beach Development Site is located in Brant, NY approximately 30 miles south of Buffalo. The area is located on Lake Erie and is approximately 54 acres in size. It is principally comprised of summer homes, about 120 people in the summer, and some full time residences, about 45 people. The site is quite flat with a slight slope to the southwest (toward Lake Erie). The soils are till and glacial lake deposits composed of dark gray and brown silty clay.

B. Historical Use and Problem Discussion

There was about a mile of soil/gravel roadways in the area. From 1968 to 1978, the Wide Beach Home Owners Association applied about 40,000 gallons of waste oil to roads for dust control. Some of that oil was contaminated with polychlorinated biphenyls (PCBs.) This problem was compounded in 1980 when, during the installation of a sanitary sewer line, the surplus excavated soil was used as fill in several yards and in a nearby "common" area known as the Grove. During remedial investigations, concentration of PCBs up to 1026 mg/Kg were observed in the soils (one sample in a catch basin had 5300 mg/Kg.) As an interim measure, the roads in the area were paved with asphalt.

C. Studies and Record of Decision

Prior to the Record of Decision, Erie County, NUS Corporation, and EA Engineering, Science, and Technology conducted studies of the area during various periods between approximately 1982 to 1985. The EPA Region 2 administrator signed a Record of Decision on September 30, 1985. The selected remedy as conceived then was excavation of PCB-contaminated soils in the roadways, drainage ditches, driveways, yards, and wetlands with disposal of the contaminated asphaltic material, and reusing uncontaminated asphaltic material in repaving. Chemical treatment of the PCB-contaminated and other general site activities. The specific treatment process was selected to be potassium polyethylene glycol (KPEG) treatment of the soil slurried with reagent in a continuous chemical treatment reactor, followed by a rotary kiln to raise the soil slurry temperature to approximately 100 degrees C. The slurry would then have been separated by sedimentation with some recovery of reagents followed by washing and placement as fill. As originally proposed approximately 37,600 yd^3 of soil and sediment would be excavated. Estimated capital costs in the ROD were about $9M.

D. Treatability Studies

During the late spring of 1988, Ebasco, working with Galson Research, performed trial runs using the KPEG process at the site. Soil was processed in batch reactors of about 200 lbs per batch. A full-scale batch processor was conceived to process about 56,000 lbs per batch. For each 200 lbs of soil, 120 pounds of reagent was composed of 1:1:1:1:2 proportions of potassium hydroxide (KOH), water, polyethylene glycol(PEG), triethylene glycol-methyl ether- higher homologs (TMH), and dimethyl-sulfoxide(DMSO). Optimum reactions occurred with a residence time of between 4.5 and 7 hours at 150 degrees centigrade. Initially, the reagents were to be recovered by filtration(early laboratory characterization had suggested low clay content), but during the site trial studies, the materials that were processed had a high clay content and required centrifuging. A total of 10 runs were conducted at the site. Based on the pilot work reagent costs were estimated to be about $65/ yd^3. Ebasco estimated that the total processing costs would be about $291/ yd^3 for reaching a 2 ppm cleanup level. At that rate the 37,000 yd^s of soil would have cost about $10M, not including such items as excavation and handling.

E. Construction Award

Designs and specifications were prepared by Ebasco Corporation and the Kansas City District of the Corps of Engineers advertised the contract as a request for proposal (RFP) on May 9, 1989. Estimates of the volume of contaminated material after design data collection was 19,000 yd^3. The estimated amount to be treated was 21,000 tons. As a "175 start", the contract was awarded on October 16, 1989 to Kimmins Corporation for $15.5M (based on the 19,000 yd^3, this represents as total cost of about $815/yd^3.

II. Process Description

A. Original Concept

The method as developed during the pilot studies performed during design was a batch process. Fine soil was to be blended with KPEG and hot potassium hydroxide. Kimmins had proposed to allow this mixture to blend for a minimum of 12 hours. The mixture was then to be transferred by sludge pumps to a centrifuge for dewatering and then washing. The reagents were to be recovered through evaporation and distillation and then reused, if possible.

B. Value Engineering (VE) Proposal

In February of 1990, the Corps of Engineers received a Value Engineering proposal from Kimmins. The proposal was evaluated and given conditional approval pending a successful site demonstration of the process. After review by the Corps, EPA, and Ebasco, the Corps tentatively approved the VE proposal. As a part of any VE proposal after award the Contractor is required to submit at least equivalent information to that in the initial proposal. Because a field tests of the Galson batch process was performed as required by the ROD, before the Corps could fully accept the VE proposal, a field demonstration of the proposed system demonstrating dechlorination was required. Kimmins elected to mobilized their full-scale equipment for this demonstration at no cost to the government.

The VE proposal suggested replacement of the batch process with a continuous operation and replacement of the KPEG process with an alkaline polyethylene glycol (APEG) process developed and patented by EPA and integrated into a thermal treatment system called the AOSTRA-Taciuk processor. The VE proposal suggested that the combination of vigorous mixing and higher temperature would accelerate the APEG dechlorination. The following is a discussion of the process as described in the VE proposal:

1. Chemistry

Whereas the KPEG process used a combination of potassium hydroxide, ethylene glycol, and DMSO at temperatures of about 100 to 150 degrees centigrade, the EPA process increase the ratio of water and decreased the relative concentrations of ethylene glycol and alkaline additives. Under the VE proposal, a modification of the EPA method, the soil temperatures in the first reaction chamber (preheat) were projected to be about 200 degrees C (450F) followed by a retort section that was to achieve temperatures of about 580 degrees C (1100F.) The purpose of the higher temperature section was to separate the oily materials and any residual PCBs from the dechlorination step. The consequences are that the PCB levels in the circulating oil rises to an equilibrium level.

2. Extraction

The general layout of the processor is Figure 1. It is composed of a multi-chambered rotary kiln. These sections are the preheat, retort, combustion, and cooling. The preheat section temperature vaporizes water and the volatile organics. The retort section is hot enough to vaporize heavy oils and PCBs. This section also results in cracking of hydrocarbons resulting in coke formation which exits with the soil. The retort section is sealed to less than about 3 per cent oxygen. Hydrocarbon vapors are drawn off of this section. The outer shell of the kiln allows the soil to travel back toward the feed end where

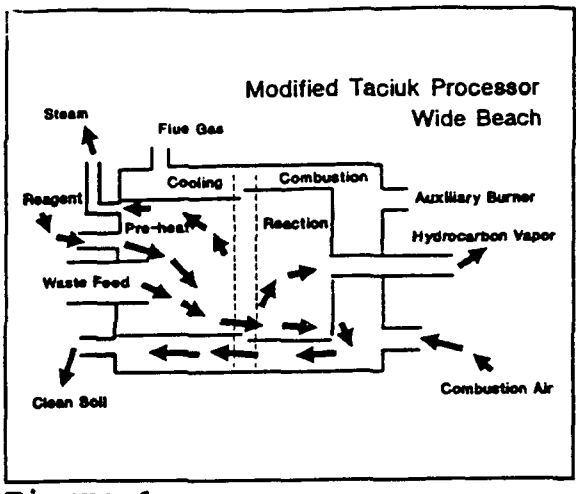


Figure 1

some is recycled to the retort section. In the combustion chamber, the coked soil is burnt and heat is reclaimed. The treated soil cools in the last section of the kiln. Collection and treatment of the off-gasses is also performed for air emissions control. Vapor driven off in the retort section passes through hot cyclones to remove particulate, cooled in a packed column (to maintain effective PCB removal with the oil, the system requires additional oil to be added to maintain a charge of oil in the column, this diesel oil is recycled and blended with the feed stream.) Following the packed column, the vapors are fed into water-cooled condensers. Excess liquids collected from the process is collected in an off-line storage tank and periodically removed for disposal.

III. Development Status

A. Mobilization

To demonstrate the applicability of the proposed VE alternative, Kimmins mobilized the treatment unit in September of 1990. This approach allowed the contractor to perform the ROD required trial tests.

B.Trial Test

The purpose of the field test was to demonstrate that dechlorination of the PCBs was occurring as shown by a disappearance of PCBs in the treated soil and documentation that the PCB inventory of the system show a decline when the PCB feed is suspended. This objective was not met because of the larger volume of recycle oil allowing only 20 percent of the recovered oils to be recycled before the test end, and further complicated because during the contaminated feed phase, less PCBs accumulated in the recycled oil than expected. Another objective was to demonstrate no transfer of the PCBs to the aqueous condensate. A maximum of 2 ppm of PCB were allow to be present in the treated soils. A total of 61.66 tons of contaminated material were processed during the trial runs over a period of 7.62 hour (8.1 tons/hour.) Air emissions initially failed because of tears in the bag-house, a later rerun of the process demonstrated the ability to meet with particulate criteria. A total of 4.96 pounds of PCBs were fed to the system, 25.2 percent of the material remained in the process oils and .3 percent remained in the soil. Assuming this amount was distributed in the 61.66 tons of material, the average influent concentration would be 40 ppm. The contractor estimated that 76 percent of the PCBs were destroyed in the first pass through the unit.

C. Total Processed

Following the trial burn and evaluation of the test results, the contractor began excavation and processing of the site materials. To optimize the use of the treatment and cut lines, the Corps construction office is extensively sampling the area prior to excavation. Through this process, closer cut lines have been defined. In addition, certain areas originally thought to be contaminated but unsampled, were found to be clean. Approximately 80 percent of the material has been excavated and treated. The throughput rate has been closer to 108 tons/day for the unit rather than the estimated 240 tons/day project in the VE proposal.

D. Excavation activities

These slides show some of the excavation and activities taking place in the residential area. As can be seen, the homeowners are enduring inconveniences. The Corps construction representatives are working day to day with the homeowners to minimize these inconveniences. As an example, one elderly lady, whose driveway and yard are being remediated, calls the construction office when she needs help getting her groceries into the house. The construction office is glad to help in this situation because of the need to promote good will.

XII. Other Considerations

One of the principal problems that has occurred at the site is the characteristic of the treated material. Originally the treated material was to have been used as backfill replaced on site after treatment. A problem has developed that precludes this usage. Although the physical placement of the material can be achieved according to the specification. The treated material becomes "quick" when water is applied. One can walk across the material but slight vibrations result in loss of bearing strength. The reasons for the "quick" conditions are still being investigated. Nonethe-less, an alternate method of disposal is now required.

Additional materials characterization of the site could have benefitted the project, by allowing a more precise delineation of the contaminated areas. Particular attention to the more traditional materials handling properties could also answer some of the questions on the "quick" characteristics. These soil behavior characteristics should also be evaluated as a part of any demonstration runs.

Changes in monitoring requirements as a result of VE proposals after award should also be a part of the assessment of process. Modification of parameters and sampling frequency may be appropriate, particularly if the VE proposal involves significantly different equipment or processes. For example, test evaluations could include monitoring of baghouse ash concentrations during the testing, monitoring for petroleum hydrocarbons in the treated soil, and monitoring changes in the physical soil properties as it passes through the process. Another area that is important to the evaluation of the trial is to have detailed process flow diagrams updated as constructed at the site prior to the test.

In a very intensive process engineering system such as at this site should require frequent visits by chemical/process engineers as a part of the construction oversight team. The process engineer, by living with the system for more than just a few days, may be able to identify problems that would otherwise go undetected. Further, the design chemists and process engineers need to have near "real-time" access to the data that is being generated from the treatment. A better evaluation and support for the construction activity could be achieved by better feedback to the designers, such as information on reagent usage, process operating conditions, and chemical analyses.

As to the applicability and effectiveness of the process used at Wide Beach, conclusions cannot be totally drawn until all the costs have been accounted and a total review of the data performed. The treatment system appears to be reducing the PCB levels to non- detectable levels in the soil (approximately 4 ppb.)

Bibliography

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United States Environmental Protection Agency
Office of Research and Development
Cincinnati OH 45268

EPA

BCD: An EPA-Patented Process for Detoxifying Chlorinated Wastes

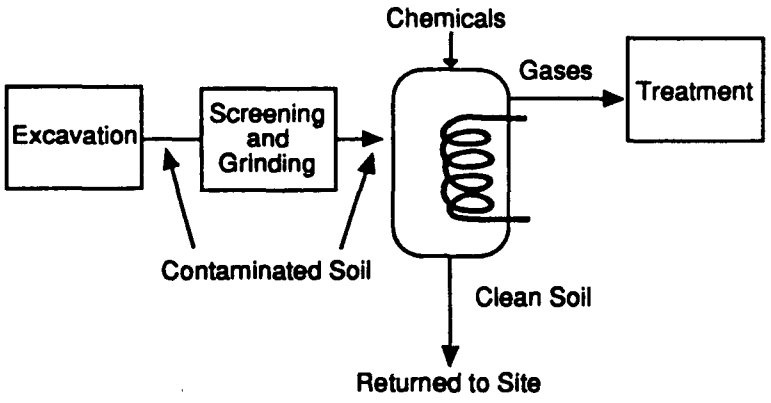
Problem of Chlorinated Wastes

- Many chlorinated organic products of commerce are toxic, and because of past industrial practices, these compounds are found at toxic levels in the environment. While pollution prevention measures will greatly diminish chances of future contamination, cost-effective and efficient treatment technologies are badly needed to remove risk to health and ecosystems from the exposure of these compounds. Incineration is an option, but is very expensive for most applications, and does not enjoy public support.
- An estimated 1 billion tons of soil in the U.S. are contaminated with chlorinated organic compounds. Of these toxic compounds, the most frequently found are polychlorinated biphenyls (PCBs), used as a dielectric in transformers, and polychlorinated phenols (PCPs), used as a wood preserving substance.
- Sediments in lakes, harbors and rivers all across the country are also contaminated with chlorinated organic wastes.
- Many obsolete pesticide formulations, such as the materials stored in Byers Warehouse in St. Joseph, MO, contain toxic chlorinated organics, and must be disposed of in an environmentally acceptable manner.

The BCD Process, an EPA invention

- Charles Rogers and coworkers at the Risk Reduction Engineering Laboratory have been working on detoxifying chlorinated organics for over ten years. They focused their efforts on contaminated soils, and developed several chemical treatment processes that are described as base-catalyzed dechlorination (BCD) processes. Unlike the earlier versions that use polyethylene glycol (PEG), the latest version of this technology uses no PEG, and represents new chemistry for dechlorination. This new mechanism is a breakthrough in treatment technology, and provides clean and inexpensive reaction.
- Unlike incineration, BCD processes offer lower cost of decontamination, reduced air pollution risk, and greater public acceptance.
- The process embodies the following steps: mixing the chemicals with the contaminated matrix (such as excavated soil or sediment, or liquids, containing these toxic compounds), heating the mixture at 340°C for several hours. The off-gases are treated before releasing to the atmosphere. The treated remains of the reactor are non-hazardous, can be either disposed of according to standard methods, or further processed for separating components for reuse.

FLOW CHART:



Large-Scale Application of BCD Process

- In Stockton, CA, the BCD process will be used to decontaminate PCB-contaminated soil in a Navy site in June, 1991. This event will be conducted under EPA's Superfund Innovative Technology Evaluation (SITE) program. Upon successful completion of this demonstration, a follow-up decontamination will be done in Guam by the Navy.
- In cooperation with Region 7, RREL is attempting to apply BCD technology to dechlorinating liquid and solid formulations of several banned herbicides (containing dioxin) at St. Joseph, MO. Recent laboratory tests have yielded promising results. Optimization of reaction conditions and engineering research are ongoing for scaling up the process from laboratory to large-scale operation.
- For treatment of contaminated soils, the BCD technology is being made ready for licensing for commercial use. Several companies have shown strong interest in licensing the technology.

Status of BCD Technology

- New applications are being sought in treating mixed wastes (organics mixed with radioactive materials), in collaboration with the Department of Energy.
- Engineering research is being conducted for process optimization and scale-up.
- The technology is available through licensing for commercial use.

United States Environmental Protection Agency | Solid Waste And Emergency Response (OS-220) | Directive 9200 5-254FS November 1989

EPA

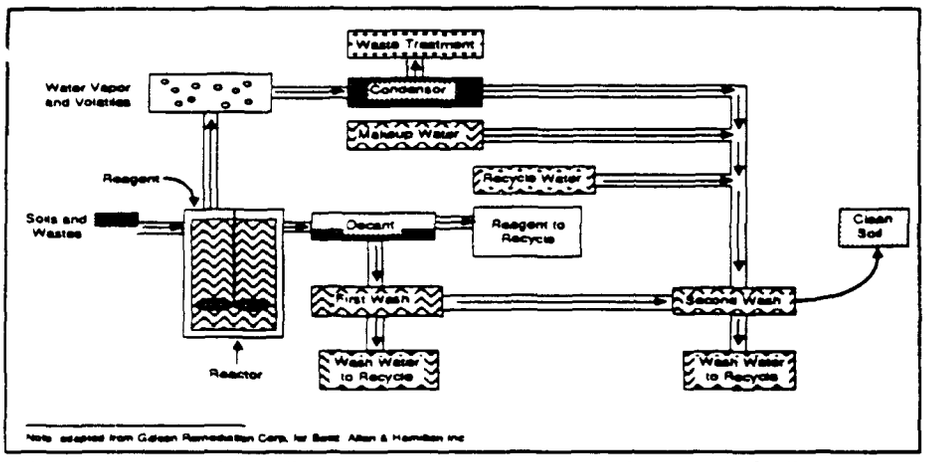
Innovative Technology

Glycolate Dehalogenation

TECHNOLOGY DESCRIPTION

The glycolate dehalogenation process is potentially effective in detoxifying specific types of aromatic organic contaminants, particularly dioxins and polychlorinated biphenyls (PCBs). The process involves heating and physically mixing contaminated soils, sludges, or liquids with an alkali metal hydroxide-based polyethylene glycol reagent in a mobile batch reactor. A typical glycolate dehalogenation treatment facility is shown above in Figure 1.

Figure 1: Schematic Diagram of a Typical Glycol Dehalogenation Treatment Facility



Before treatment, soils are sieved to remove any large rocks and/or debris. The contaminated media are commingled with a reagent to form a homogeneous slurry. The reagent primarily consists of potassium or sodium hydroxide (KOH or NaOH) and polyethylene glycol (PEG); other reagents such as dimethyl sulfoxide (DMSO) or sulfolane (SFLN) may be added to improve the efficiency of the process. The slurry is simultaneously heated (25°C to 150°C) and mixed, consequently decomposing halogenated contaminants into less toxic, water-soluble compounds (glycol-ethers and chloride salts).

Treatment time in the reactor ranges from 0.5 to 5 hours, depending on the contaminant type, initial concentration of the contaminant, water content, humic and clay content (for soils), and the level of treatment desired. Water is vaporized in the reactor and collected in a condensate receiver. A carbon adsorption filter traps any volatile compounds that are not condensed.

Additional treatment of soils is required to desorb reaction by-products and reagent from the dechlorinated soil. This treatment includes physically mixing the dehalogenated soil with water in successive washing cycles. The treated soil is then dewatered and redeposited on-site, while the reagent and wash waters are recycled and ultimately treated and/or delisted.

Advantages of glycolate dehalogenation include toxicity reduction of target contaminants, mobility of treatment unit, short treatment time, non-toxic by-products, and cost-effectiveness relative to conventional technologies for similar wastes (e.g., incineration).

Disadvantages are that the technology is limited to halogenated compounds, and spent reagent, wastewater, and by-products may require further treatment and/or disposal actions. Applications and limitations of glycolate dehalogenation are further discussed in the following sections.

SITE CHARACTERISTICS AFFECTING TREATMENT FEASIBILITY

Glycolate dehalogenation may be used to treat multimedia waste containing aromatic halides such as dioxins, PCBs, and chlorobenzenes. The effectiveness of this treatment on general contaminant groups is provided in Table 1; however, treatability tests are required to determine the effectiveness of glycolate dehalogenation for specific site conditions.

Factors limiting the effectiveness of glycolate dehalogenation include highly concentrated contaminants, high water content, low pH, high humic content (soil), and the presence of other alkaline-reactive materials (e.g., aluminum, other metals). Site-specific characteristics and their potential impact are provided in Table 2.

Table 1
Effectiveness of Glycol Dehalogenation Treatment on General Contaminant Groups for Soil and Debris

	Treatability Groups	Effectiveness
Organics	Halogenated volatiles	◒
	Halogenated semi-volatiles	◒
	Non-halogenated volatiles	○
	Non-halogenated semi-volatiles	○
	PCBs	●
	Pesticides	◒
	Dioxins/Furans	●
	Organic cyanides	○
	Organic corrosives	○
Inorganics	Volatile metals	○
	Non-volatile metals	○
	Asbestos	○
	Radioactive materials	○
	Inorganic corrosives	○
	Inorganic cyanides	○
Reactive	Oxidizers	○
	Reducers	○

Demonstrated Effectiveness ● | No Expected Effectiveness ○
Potential Effectiveness ◒ | Potentially Detrimental X

Table 2: Site-Specific Characteristics and Impacts on Glycolate Dehalogenation Treatment

Characteristics Impacting Process Feasibility	Reasons for Potential Impact	Actions to Minimize Impacts
Elevated concentrations of chlorinated organics (greater than 5 percent)	Requires excessive volumes of reagent; process less cost-effective	Reagent addition
Presence of aliphatic organics, inorganics, and metals	Glycolate dechlorination ineffective against these waste groups	Employ supplemental treatment technology (e.g., solvent extraction, soil washing)
High water content in waste (greater than 15 percent)	Requires excessive volumes of reagent and increased energy input; process less cost-effective	Reagent addition; evaporation of water during treatment process
Low pH (less than 2)	Requires excessive volumes of reagent; process less cost-effective	Reagent addition, pH adjustment
Presence of other alkaline-reactive materials (e.g., aluminum, other metals)	Reactive materials compete with contaminants for reagent	Reagent addition
High humic content in soil	Increases reaction time, process less cost-effective	Increase reactor time

TECHNOLOGY CONSIDERATIONS

The major technology consideration is determining how a large volume of residual wastewater generated from the soil washing/dewatering process will be managed. The residual effluent may require treatment prior to disposal; however, if the volume of waste water is extremely high (i.e., volumes generated from greater than 30,000 cubic yards of washed soil), it may be more cost-effective to petition EPA to delist the residual effluent, whereby it may be disposed without further treatment. Post-treatment options commonly employed when treating residual wastewaters may include chemical oxidation, biodegradation, carbon adsorption, precipitation, or incineration.

Glycolate dehalogenation operations require no special handling [although special handling of contaminated media (e.g., dioxin contaminated waste) may be required] and energy requirements are not extreme; therefore, operation and maintenance costs are relatively low. A full-scale dehalogenation unit with a capacity of 80 cubic yards per batch requires an average of 670 kilowatts, with 930 kilowatts peak. A sufficient power source is required and may present additional costs if a source is not readily accessible. Preconstruction engineering controls, to guard against accidental spills, include leveling and lining (synthetic) the areas under and adjacent to the treatment facility and diking the area surrounding the facility.

TECHNOLOGY STATUS

Numerous vendors presently possess the technology to conduct full-scale glycolate dehalogenation. Galson Remediation Corporation (GRC) has reported to have successfully applied full-scale glycolate dehalogenation at two sites containing PCB-contaminated waste oil. The GRC full-scale reactor has a single batch capacity of 80 cubic yards and is designed to treat 160 to 200 cubic yards of waste per day. GRC quotes the average cost of a treatability test is between $2,000 and $3,000, depending upon the chemistry of the target contaminant(s). Treatment costs range from $100 to $300 per cubic yard; actual costs are contingent upon site-specific characteristics. A summary of vendors capable of conducting pilot- and/or full-scale treatment are listed in Table 3.

Mobile glycolate dehalogenation units have been field-tested on various waste types and media at numerous CERCLA sites at the bench- and pilot-scale. These sites include:

- Montana Pole Wood Preserving Site, Butte, Montana - An oily phase liquid containing 3.0 percent (30,000 ppm) pentachlorophenol (PCP) and oil containing up to 84 ppm chlorinated dioxins and furans were treated to below their respective detection limits. In total, 9,000 gallons of contaminated oil were treated within 1.5 hours.
- Western Processing Site, Kent, Washington - Heterogeneous mixtures of oil, solids, and water containing pesticide phosphate esters and TCDD (up to 120 ppb) were treated to below their respective detection limits. In total, 7,550 gallons of waste were treated within 13 hours.
- P.W.C., Guam - Soils contaminated with Aroclor 1260, ranging in concentrations from 300 ppm to 2,200 ppm, were treated to below 2 ppm within 5 hours. The high temperature alkaline-glycol treatment process, developed by EPA, operates efficiently without adding DMSO or SFLN.

EPA has selected glycolate dehalogenation as a component of the selected remedy for three CERCLA sites. Site names, ROD sign dates, target contaminants, waste volumes, and media are provided in Table 4.

Table 3
Vendor Information

Company	Contact	Address
Galson Remediation Corporation (dechlorination)	Robert Peterson Edwina Miloc	6627 Joy Road E. Syracuse, NY 13057 (315) 436-5160
S D Meyers, Inc. (dechlorination)	Joe Kelly	180 South Ave Tallmage, OH 44278 (216) 633-2666
Chemical Waste Management (dechlorination)	Dick Rosenberg	150 W 137th St. Riverdale, IL 60627 (312) 841-8360
U.S. EPA, Risk Reduction Engineering Laboratory (dehalogenation)	Alfred Kornel Charles Rogers	26 W Martin Luther King Drive Cincinnati, Ohio 45268 (513) 569-7421 or 569-7757

OFFICE OF RESEARCH AND DEVELOPMENT CONTACTS

Supplemental information concerning glycolate dehalogenation may be obtained from Charles Rogers, U.S. EPA, Risk Reduction Engineering Laboratory, Cincinnati, Ohio 45268, (513) 569-7757 or FTS 684-7757.

Table 4
Glycolate Dehalogenation at CERCLA Sites

SELECTED:		
Region 1 - Re-Solve, MA 9/87	PCBs in Sediment, Soil	3,000 cubic yards sediment 22,500 cubic yards soil
Region 2 - Wide Beach, NY 9/86	PCBs (Arochlor 1254) in Soil	28,600 cubic yards
Region 6 - Sol Lynn, TX 3/88	PCBs in Soil	Not provided

United States Environmental Protection Agency	Office of Emergency and Remedial Response Washington, DC 20460	Office of Research and Development Cincinnati, OH 45268
Superfund	EPA/540/2-90/015	September 1990

EPA

Engineering Bulletin
Chemical Dehalogenation Treatment: APEG Treatment

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants and contaminants as a principal element." The Engineering Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial investigation scoping needs. Addenda will be issued periodically to update the original bulletins.

Abstract

The chemical dehalogenation system discussed in this report is alkaline metal hydroxide/polyethylene glycol (APEG) which is applicable to aromatic halogenated compounds. The metal hydroxide that has been most widely used for this reagent preparation is potassium hydroxide (KOH) in conjunction with polyethylene glycol (PEG)[6, p. 461]* (typically, average molecular weight of 400 Daltons) to form a polymeric alkoxide referred to as KPEG [16, p. 835]. However, sodium hydroxide has also been used in the past and most likely will find increasing use in the future because of patent applications that have been filed for modification to this technology. This new approach will expand the technology's applicability and efficacy and should reduce chemical costs by facilitating the use of less costly sodium hydroxide [18]. A variation of this reagent is the use of potassium hydroxide or sodium hydroxide/tetraethylene glycol, referred to as ATEG, that is more effective on halogenated aliphatic compounds [21]. In some KPEG reagent formulations, dimethyl sulfoxide (DMSO) is added to enhance reaction rate kinetics, presumably by improving rates of extraction of the haloaromatic contaminants [19][22].

Previously developed dehalogenation reagents involved dispersion of metallic sodium in oil or the use of highly reactive organosodium compounds. The reactivity of metallic sodium and these other reagents with water presented a serious limitation to treating many waste matrices; therefore, these other reagents are not discussed in this bulletin and are not considered APEG processes [1, p. 1].

The reagent (APEG) dehalogenates the pollutant to form a glycol ether and/or a hydroxylated compound and an alkali metal salt, which are water soluble byproducts. This treatment process chemically converts toxic materials to non-toxic materials. It is applicable to contaminants in soil [11, p. 1], sludges, sediments, and oils [2, p. 183]. It is mainly used to treat halogenated contaminants including polychlorinated biphenyls (PCBs) [4, p. 137], polychlorinated dibenzo-p-dioxins (PCDDs) [11, p. 1], polychlorinated dibenzofurans (PCDFs), polychlorinated terphenyls (PCTPs), and some halogenated pesticides [8, p. 3][14, p. 2]. This technology has been selected as a component of the remedy for three Superfund sites. Vendors should be contacted to determine the availability of a treatment system for use at a particular site. The estimated costs of treating soils range from $200-$500/ton. This bulletin provides information on the technology applicability, the types of residuals resulting from the use of the technology, the latest performance data, site requirements, the status of the technology, and where to go for further information.

Technology Applicability

This technology is primarily for treating and destroying halogenated aromatic contaminants. The matrix can be soils, sludges, sediments, or oils. If a waste site has contaminants other than halogenated compounds, other alternatives should be considered.

The concentrations of PCBs that have been treated are reported to be as high as 45,000 ppm. Concentrations were

* [reference number, page number]

reduced to less than 2 parts per million per individual PCB congener. Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) have been treated to nondetectable levels at part per trillion sensitivity. The process has successfully destroyed PCDDs and PCDFs contained in contaminated pentachlorophenol oil. For a contaminated activated carbon matrix, direct treatment was less effective and the reduction of PCDDs/PCDFs to concentrations less than 1 ppb was better achieved by first extracting the carbon matrix with a solvent and then treating the extract [15, p. 1].

All field applications of this technology to date have been in various matrices and not on specific Resource Conservation and Recovery Act (RCRA) listed wastes. The effectiveness of APEG on general contaminant groups for various matrices is shown in Table 1. Examples of constituents within contaminant groups are provided in Reference 23, "Technology Screening Guide for Treatment of CERCLA Soils and Sludges". This table is based on the current available information or professional judgment when no information was available. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the treatment efficiency achieved will be acceptable at other sites. For the ratings used for this table, demonstrated effectiveness means that, at some scale, treatability was tested to show that, for that particular contaminant and matrix, the technology was effective. The ratings of potential effectiveness and no expected effectiveness are based upon expert judgment. Where potential effectiveness is indicated, the technology is believed capable of successfully treating the contaminant group in a particular matrix. When the technology is not applicable or will probably not work for a particular combination of contaminant group and matrix, a no-expected-effectiveness rating is given.

Table 1
Effectiveness of APEG Treatment on
General Contaminant Groups for Various Matrices

	Contaminant Groups	Effectiveness: Sediments	Oils	Soil	Sludge
Organic	Halogenated volatiles	▼	▼	▼	▼
	Halogenated semivolatiles	▼	▼	▼	▼
	Nonhalogenated volatiles	☐	☐	☐	☐
	Nonhalogenated semivolatiles	☐	☐	☐	☐
	PCBs	■	■	■	■
	Pesticides (halogenated)	▼	■	■	▼
	Dioxins/Furans	■	■	■	■
	Organic cyanides	☐	☐	☐	☐
	Organic corrosives	☐	☐	☐	☐
Inorganic	Volatile metals	☐	☐	☐	☐
	Nonvolatile metals	☐	☐	☐	☐
	Asbestos	☐	☐	☐	☐
	Radioactive materials	☐	☐	☐	☐
	Inorganic corrosives	☐	☐	☐	☐
	Inorganic cyanides	☐	☐	☐	☐
Reactive	Oxidizers	☐	☐	☐	☐
	Reducers	☐	☐	☐	☐

■ Demonstrated Effectiveness: Successful treatability test at some scale completed
▼ Potential Effectiveness: Expert opinion that technology will work
☐ No Expected Effectiveness: Expert opinion that technology will not work

Limitations

The APEG technology is not intended as an in situ treatment. APEG will dehalogenate aliphatic compounds if the mixture is reacted longer and at significantly higher temperatures than for aromatic compounds, it is recommended that a related reagent KTEG be considered for these contaminants. KTEG has been shown at laboratory scale to be effective on halogenated aliphatic compounds such as ethylene dibromide, carbon tetrachloride, ethylene dichloride, chloroform, and dichloromethane (methylene chloride) [18, p. 2]. The necessary treatment time and temperature for KTEG use can be determined from laboratory tests.

Treatability tests should be conducted prior to the final selection of the APEG technology to identify optimum operating factors such as quantity of reagent, temperature, and treatment time. These tests can be used to identify such things as water content, alkaline metals and high humus content in the soils, glycol extractables content, presence of multiple phases, and total organic halides that have the potential to affect processing times and costs [19].

The treated soil may contain enough residual reagent and treatment byproducts that their removal could be required before final disposal. If necessary, such byproducts are usually removed by washing the soil two or three times with water. The soil will have to be neutralized by lowering the pH prior to final disposal.

Specific safety aspects for the operation must be considered. Treatment of certain chlorinated aliphatics in high concentrations with APEG may produce compounds that are potentially explosive (e.g., chloroacetylenes) and/or cause a fire hazard. The use of DMSO or similar reagents may lead to formation of highly flammable volatile organics (e.g., methyl sulfide) [18, §IV C]. Severe corrosivity can be a concern when DSMO is teamed with other APEG reagents. Alkaline reactive materials such as metallic aluminum will compete with the contaminants for the reagent and may produce hydrogen gas (explosive). Vapors from heating oily soils, which are often the matrix in which PCBs are found, can also create such potential problems as fires and noxious fumes. These problems can often be solved by taking appropriate corrective actions during elevated temperature processing.

The operation must also be conducted with care because of the elevated temperatures and production of steam, the use of caustics in the process, and the presence of acids that are used for neutralization. If DMSO is used, care must be taken to prevent its coming into contact with skin, for it enhances transport of PCBs through the skin, thus increasing the risk of exposure.

Technology Description

Figure 1 is a schematic of the APEG treatment process.

Waste preparation includes excavation and/or moving the soil to the process where it is normally screened (1) to remove debris and large objects and to produce particles that are sufficiently small to allow treatment in the reactor without binding the mixer blades.

Typically, the reagent components are mixed with the contaminated soil in the reactor (2). The material must be well mixed with the reagent to allow effective treatment. Treatment proceeds inefficiently without mixing. This mixture is heated to between 100° and 180° C. The reaction proceeds for 1 to 5 hours depending upon the type, quantity, and concentration of the contaminants. The treated material goes from the reactor to a separator (3) where the reagent is removed and can be recycled (4).

During the reaction, water is vaporized in the reactor, condensed (5) and collected for further treatment or recycled through the washing process, if required. Carbon filters (7) are used to trap any volatile organics that are not condensed. In the washer (6), the soil is neutralized by the additions of acid. It is then dewatered (8) before disposal.

Process Residuals

There are three main waste streams generated by this technology: the treated soil, the wash water, and possible air emissions. The treated soil will need to be analyzed to determine if it meets the regulatory requirements for the site before final disposition can be made. The soil's pH must be adjusted before disposal. The chemistry of this technology is specific to halogenated organics and, based upon a test conducted by the EPA in 1985, results in byproduct compounds that appear to be neither toxic nor of concern. In that test the EPA checked for 1) mutagenicity, 2) toxicity, and 3) bioaccumulation/bioconcen-tration of the byproducts of two different contaminants: tetrachlorobenzene and 2,3,7,8 - TCDD that had been treated by the process [3, p. 80]. The individual byproduct chemical compounds were not determined. These compounds and the residual levels of reagent or catalyst did not present a serious health or environmental problem [12, p. 2].

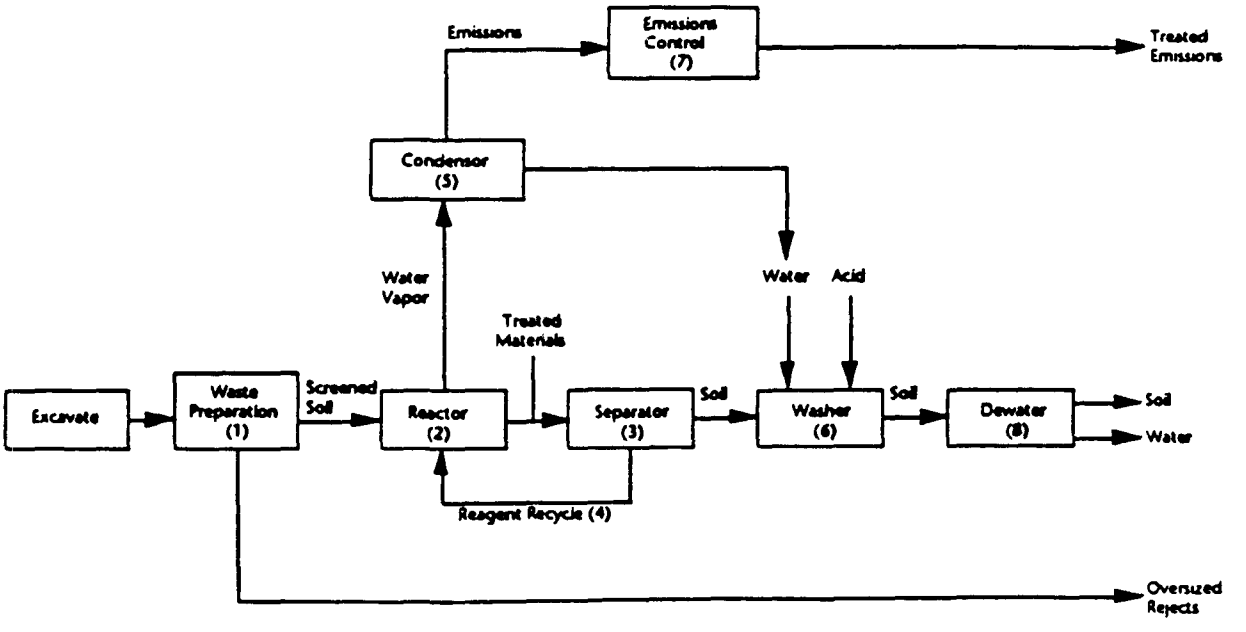
Waste wash water contains only trace amounts of contaminants and reagents and would be expected to meet appropriate discharge standards, enabling it to be discharged to a local, publicly owned treatment works or receiving stream. Volatile air emissions can be released due to the heating and mixing that occurs with the process. They are usually captured by condensation and/or on activated carbon. The contaminated carbon is usually incinerated.

Site Requirements

APEG treatment units are transported by trailers [13,p. 54]. Therefore, adequate access roads are required to get the unit to the site. The system that operated in Guam, which used a 1.5- ton batch reactor, required an area of 100 feet by 100 feet.

Energy requirements involve heating the reactor and removing the water by volatilization. For the reactor used in Guam, a standard 440V, three-phase electrical service was required along with a diesel steam-generating plant rated at

Figure 1
APEG Treatment Process



600 lb/h and 80 psi [13, p. 53]. A standard municipal water supply, or equivalent, is adequate for this process.

Contaminated soils or other waste materials are hazardous and their handling requires that a site safety plan be developed to provide for personnel protection and special handling measures.

A means of containing and cleaning up accidental spills must be provided. The reagents (KOH, acids, etc.) should be stored in drums with containment beneath and provisions to pump any spills to a holding area for neutralization [19, p. 2].

The process residuals normally must be stored until their level of contaminants are verified to be below those established for the site. Depending upon the site, a method to store waste may be necessary. Storage capacity will depend on waste volume.

Onsite analytical capabilities are highly desirable. Extraction equipment and gas chromatography/mass spectometer capabilities should be available to measure contaminants of interest and to provide information for process control.

Performance Data

This technology's performance has been evaluated from bench-scale tests to field tests in large reactors. Table 2 summarizes the results of several more important applications of the technology and their results.

RCRA Land Disposal Restrictions (LDRs) that require treatment of wastes to best demonstrated available technology (BDAT) levels prior to land disposal may sometimes be determined to be applicable or relevant and appropriate requirements (ARARs) for CERCLA response actions. The APEG treatment technology can produce a treated waste that meets treatment levels set by BDAT, but may not reach these treatment levels in all cases. The ability to meet required treatment levels is dependent upon the specific waste constituents and the waste matrix. In cases where APEG treatment does not meet these levels it still may, in certain situations, be selected for use at the site if a treatability variance establishing alternative treatment levels is obtained. EPA has made the treatability variance process available in order to ensure that LDRs do not unnecessarily restrict the use of alternative and innovative treatment technologies. Treatability variances may be justified for handling complex soil and debris matrices. The following guides describe when

Table 2
APEG Field Performance Data

Site/Date	*Contaminant/ Waste Form*	*Concentration Before*	*Concentration After*	*Volume Treated*
Signo Trading NY/1982	dioxin/liquid	135ppb	<1 ppb	15 gallons
Montana Pole Butte, MT/1986 (16, p. 838) [5, p. 1]	dioxin furans/oil	147-83,923 ppb	<1 ppb	10,000 gallons
Western Processing Kent, WA/1986 [16, p. 838]	dioxin/liquid and sludge	120 ppb	<0.3 ppb	7,550 gallons
Wide Beach Erie County, NY/ 1985	PCBs (Aroclor 1254)/soil	120 ppm	<2 ppm	1 ton
Guam U.S.A./1988 793 gal. reactor [13, p. 43]	PCBs/soil	2500[a] ppm with hot spots as high as 45,860 ppm	<1[ab] ppm	22 tons soil 3.4 tons crushed rock
Bengart & Memel Buffalo, NY/1986 55 gal. drum [10, p. 13]	PCBs/soil	51 out of 52 drums, 108 ppm	<27 ppm	52 fifty-five gallon drums
Economy Products Omaha, NE/1987	TCDD, 2, 4-D, 2, 4, 5-T/liquid	1.3 ppm 17,800 ppm 2,800 ppm	ND 334 ppm 55 ppm	20 gallons

a = value is an average value

b = per resolvable PCB congener

and how to seek a treatability variance for soil and debris: Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions," (OSWER Directive 9347.3-06FS) [20]; and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-07FS) [17]. Another approach could be to use other treatment techniques in series with APEG treatment to obtain desired treatment levels.

Technology Status

The APEG process has been selected for cleanup of PCB-contaminated soils at three Superfund sites: Wide Beach, New York (September 1985), Re-Solve, Massachusetts (September 1987), and Sol Lynn, Texas (March 1988). Wide Beach is expected to start operation in the summer of 1990 [9, p. 99] [19].

This technology has received approval from the EPA's Office of Toxic Substance under the Toxic Substances Control Act for PCB treatment.

Significant advances are currently being made to the APEG technology. These advances employ water rather than costly PEG to wet the soil and require shorter reaction times and less energy. These advances should greatly enhance the economics of the process. Performance information on this modified process is not available at this time for inclusion in this bulletin [18].

This technology uses standard equipment. The reaction vessel must be equipped to mix and heat the soil and reagents. A detailed engineering design for a continuous feed, full-scale system for use in Guam is currently being completed. It is estimated that a full-scale system can be fabricated and placed in operation in 6 to 12 months. Costs to use APEG treatment are expected to be in a range of $200-$500/ton.

EPA Contact

Technology-specific questions regarding APEG technology may be directed to:

Charles J. Rogers
U.S. EPA Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, Ohio 45268
Telephone: FTS 684-7757 or (513) 569-7757

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Note: A more comprehensive bibliography is being developed.

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7.0 BIOREMEDIATION

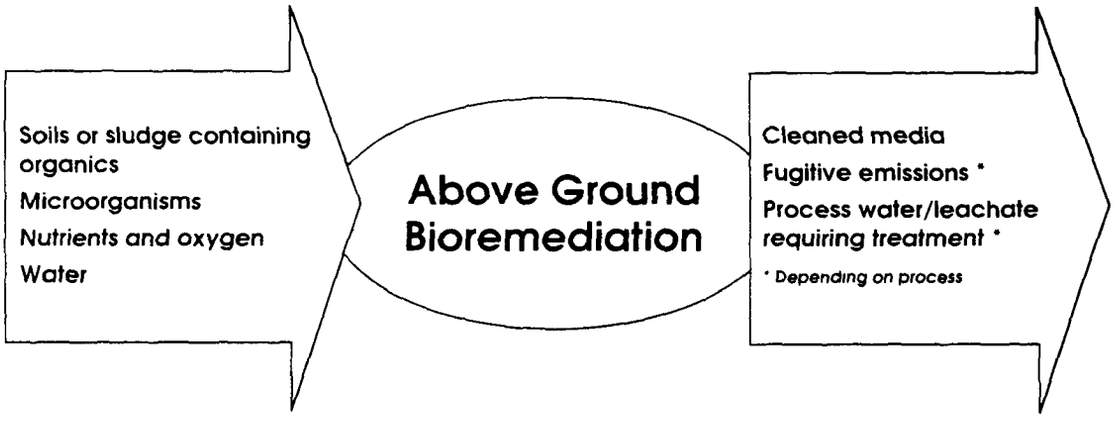
7.1 TECHNOLOGY DESCRIPTION

Bioremediation technologies involve enhancing biodegradation of contaminants through the stimulation of indigenous soil and ground-water microbial populations or the addition of proprietary, natural microbial species. Natural biodegradative processes are enhanced by optimizing conditions necessary for microbes to grow and complete metabolic pathways. Bioremediation is applicable only for treating organic contaminants.

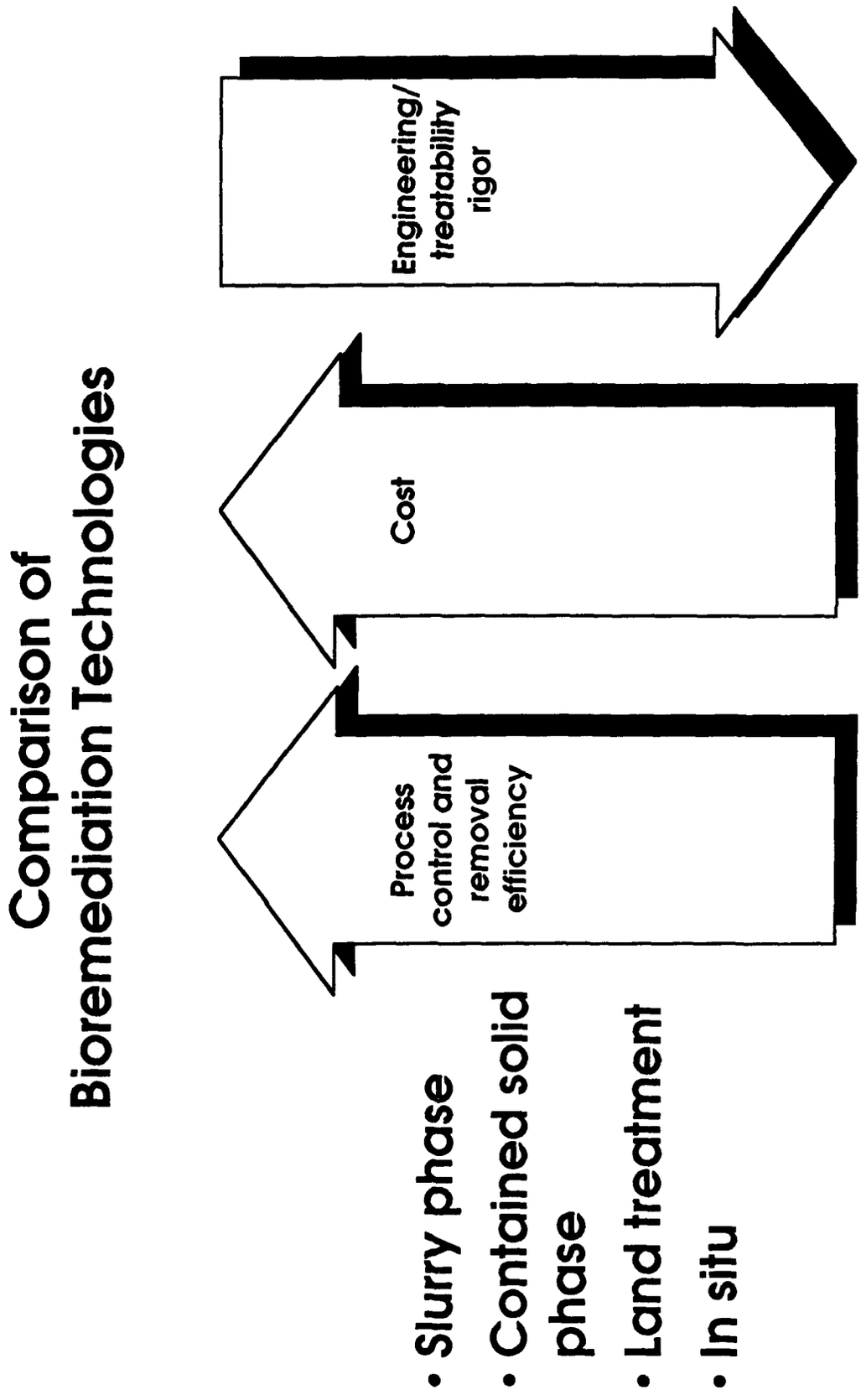
Several different types of bioremediation technologies can be utilized to treat hazardous wastes and these technologies can be classified in two broad categories:

- Above ground (including slurry phase, contained solid phase, land treatment, and composting)
- In situ

The different approaches vary in terms of the process control, time needed and cost of remediation. Exhibit 1 shows the general relationship of the different bioremediation technologies with respect to process control, cost, and amount of effort needed in the engineering/treatability testing phase of the project. Slurry phased bioremediation, for example, is the most easily controlled process and often the most expensive.



- Slurry phase
- Contained solid phase
- Land treatment


Comparison of
Bioremediation Technologies
• Slurry phase
• Contained solid phase
• Land treatment
• In situ
Process control and removal efficiency
Cost
Engineering/ treatability rigor

Slurry Phase

Slurry-phase bioremediation involves mixing of excavated soil with water to create a slurry that is mechanically agitated in an environment (usually a tank, although in situ lagoon applications are possible) with appropriate ambient conditions of nutrients, oxygen, pH, and temperature. Microorganisms may be seeded initially or added continuously throughout an appropriate residence time. Upon completion of the process, the slurry is dewatered, and the treated soil is disposed.

Land Treatment (Land Farming)

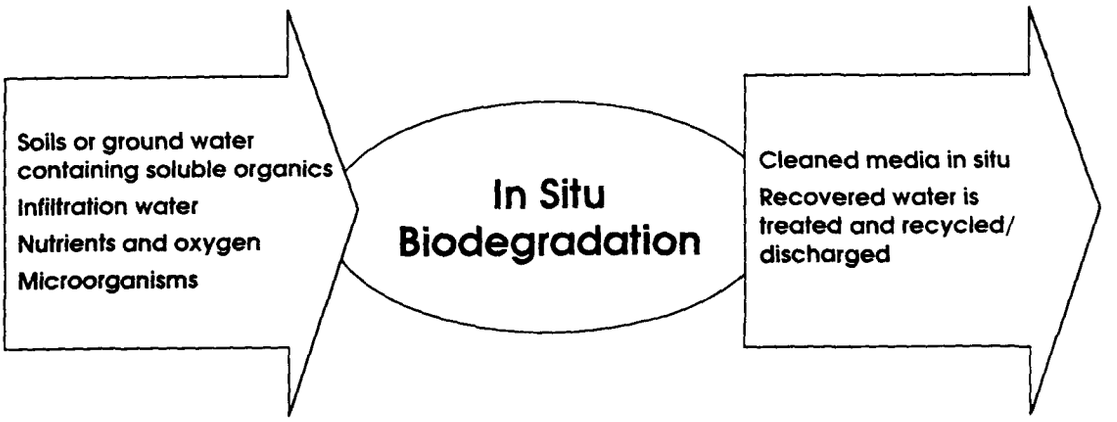
This process involves placing contaminated soil in a prepared, lined treatment bed. Wastes may be stockpiled prior to application which occurs in a series of lifts (several inches thick). Supplements such as manure or nutrients may be added and the soil is periodically cultivated. Use of standard construction/farm equipment allows management of a large area of treatment.

Contained Solid Phase

This represents a variety of processes similar to land farming, but provides greater process control. Although these systems have been used in Europe, they have not been used in this country. Excavated soils are mixed, soil amendments (water, nutrients, pH modifiers, bulk modifiers, and microbes) are added, and the conditioned soil placed in an enclosure such as a building, tank, or modified pad. This may improve process control by eliminating water run-on/off, moderating temperature, allowing greater moisture control and controlling VOC emissions. The soil may be several feet deep and require special equipment or processes for reconditioning or aeration. To the extent the building enclosure satisfies the RCRA definition of a tank, the process may be used to satisfy land ban requirements.

Composting is a solid-phase, above-ground biological treatment process in which structurally firm material is added to the contaminated material to enhance the decomposition of organic compounds. Water, oxygen and nutrients are added, too, to facilitate microbial growth. This technology has not yet been selected for use at a Superfund site although the Army has had some success using composting to degrade munitions wastes in pilot scale tests.

Composting, particularly if conducted in a closed reactor, is very similar to contained solid phase bioremediation and is included here with the discussion of contained solid phase bioremediation.



• Time: months to years

In Situ

This process promotes and accelerates the natural biodegradation processes in the undisturbed soil. Generally, it consists of a water recirculation system with above ground water treatment and conditioning of the infiltration water with nutrients and an oxygen source. The system is usually designed to allow uncontaminated ground water to enter the zone of contamination but prevents ground water from leaving the contaminated zone. Common system design consists of central withdrawal of ground water and reinfiltration through well injection or infiltration galleries at several locations around the outer border of the treated area. Biodegradation relies on the contact between contaminants (in the water phase) and microorganisms. In general, subsoil saturation is required. Oxygen is usually the limiting factor. Sources of oxygen include air, pure oxygen, and hydrogen perodixe. Although hydrogen peroxide is commonly used, it can be relatively expensive and has a variety of technical problems associated with its use. Nitrate is being researched with some success as an alternative electron receptor.

7.3 TECHNOLOGY STATUS

- Bioremediation has been selected for source control remediation at 31 Superfund sites (FY 82-90 RODs). It will be used to remedy contaminated ground water at five sites. It has been selected for five emergency response actions.
- Currently considered, planned, or operated in full-scale systems at least 140 CERCLA, RCRA, and UST sites.

- Five hazardous waste sites have been selected for field evaluation under the Bioremediation Field Initiative program. These are: Champion site, MT; Allied Signal site, MI; Hill AFB, UT; Eielson AFB, AL; Park City Pipeline Spill, KS.

Treatments for Excavated Soil

- Several slurry-phase and solid-phase biological treatment systems are commercially available.
- Land treatment (farming) was approved in 12 RODs; slurry-phase reactors have been chosen in five RODs; and solid phase bioremediation has been selected in three RODs.

In Situ Biodegradation

- A recent international survey found 23 remediation projects in the Netherlands, West Germany, and the U.S.A.
- In situ treatment has been selected for 11 NPL sites and two emergency response actions.
- There have been demonstrations that some halogenated compounds may be degraded by bacteria that use methane as their food source.

7.4 APPLICATIONS

- The U.S. Army Toxic and Hazardous Materials Agency has pilot tested composting of soils contaminated with TNT, DNT and other by products of munitions manufacture for 40 days. The original contaminants were successfully degraded and the wastes found to be non-toxic. The Army is now analyzing the product for the presence of byproducts and intermediary products of the degradation of TNT and DNT.
- The Superfund sites where bioremediation has been selected are contaminated with VOCs (sixteen sites), PAHs (twenty-one sites), SVOCs (twenty-two sites), and creosote (eleven sites). The technology has broad applications for organic wastes.
- PAH's with four or more rings are more difficult to degrade than simpler PAHs. The literature reports some success with white rot fungus (Bumpus, 1989) and Mycobacterium (Heitkamp, et al., 1988) (See Key Reference List)
- Recent treatability studies conducted at the American Creosote Works Superfund site (Muller et al. 1991) with creosote contaminated soils and sediments suggest that:
    - Solid phase bioremediation strategies may not effectively meet acceptable treatment standards for creosote contaminated soils and sediments in the time defined by the studies (90 days). Relatively poor removals of

pentachlorophenol (PCP) and other multi-ring, toxic compounds were found (0% to 50%).

- Slurry phase bioremediation strategies can be effectively employed to remediate creosote-contaminated materials. Within 14 days, 2 ring PAHs were totally degraded and the concentrations of PAHs with 3, 4, and more rings were effectively reduced. The reduction of the heavier PAHs was most significant when there was a significant concentration of phenolics and 2-ring PAHs in the contaminated material.

- These studies indicate that PAHs with two rings biodegrade more readily than those with three rings which, in turn degrade more readily than those with four rings.

- Bioremediation is appropriate for soil, sludges, sediments, ground water and surface water.

- Bioremediation may not be applicable at sites where the contaminated material contains extremely high concentrations of heavy metals, highly chlorinated organics, pesticides, herbicides, or inorganic salts. High concentrations of these contaminants may be toxic to the microorganisms needed for biodegradation.

- This technology requires that temperature, moisture content, pH, nutrient levels, and oxygen content be within the limits required by the microorganisms. In situ bioremediation may not be applicable at sites where these parameters are not within those limits.

7.5 TECHNOLOGY STRENGTHS

- The technologies have fairly broad applicability for organic wastes.

- Biological technologies are likely to be considered as natural processes and supported by the public.

- Cost effective

- Please see Exhibit 2 for additional strengths related to the different types of bioremediation.

7.6 TECHNOLOGY LIMITATIONS

- Recent treatability studies conducted at the American Creosote Work Superfund site (Mueller, et. al., 1991) with creosote contaminated soils and sediments suggest that:

    - Abiotic losses from bioremediation of creosote contaminated soils and sediments can be significant. Volatilization is more significant with the low molecular weight compounds within creosote (volatilization accounted for 12% of the observed losses of naphthalene during solid phase bioremediation of sediments) Significant quantities

of high molecular weight compounds were found adsorbed to the bioreactor sludge and residue in slurry-phased bioremediation.

- Complex waste mixtures can inhibit biological activity
- Performance is highly dependent on site conditions
- Some wastes are hard or slow to degrade
- A better understanding and optimization of the science is needed.
- Public can be fearful of microbes suspected of having been "genetically engineered."
- Please see Exhibit 2 for additional limitations related to the different types of bioremediation.

7.7 POTENTIAL MATERIALS HANDLING REQUIREMENTS

For slurry phase, land treatment, contained solid phase:

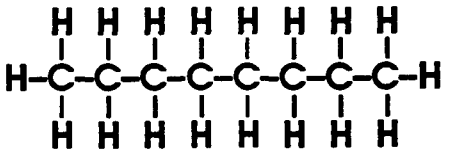
- Excavation is required.
- The waste material must be screened to remove debris and large particles.
- Size reduction techniques can be used to achieve feed size required by the equipment.
  - Slurry-phase bioremediation works best if the particles are generally less than 1/4 inch in diameter. This small size is needed to ensure adequate contact between the biomass and the contaminants and to keep the particles in suspension in the slurry.
- The pH of the waste may require adjustment. Bioremediation works only for material with a generally neutral pH (>4.5 and <8.5). If the contaminated material does not fit within this range, acid or base must be added and the material mixed. As the biological processes proceed, the pH of the material may change. The pH may need to be adjusted several times throughout the operation of the technology.
- The waste may require dewatering or wetting. Biological activity is promoted when the moisture content of the contaminated material is between 40 percent and 80 percent.
- The temperature of the wastes may be adjusted. Biological activity proceeds more rapidly under warm conditions. Generally, bioremediation projects should be operated between 60° F and 110° F.
- The waste material, water, added nutrients, and oxygen will need to be mixed to promote microbial growth.

Technique	Strengths	Limitations
Slurry Phase	• Offers most control of the physical/chemical environment • Most certain process to monitor in terms of effectiveness • Enclosed reactors can capture fugitive volatile emissions • Provides highest biological reaction rates • Offers capability to treat the broadest range of organic compounds and soil types, i.e., treat the most difficult to biodegrade • Treatability testing and engineering scale-up for this technology is relatively simple	• Considerable energy may be required to keep soil in suspension, thereby adding to cost. Pretreatment may be necessary to remove dense material (gravel, stones, etc.) • Tanks or containers need to meet appropriate RCRA standards, including requirements for secondary containment
Land Treatment (Farming)	• Relatively maintenance-free operation. Soil is applied in lifts which are several inches thick and periodically cultivated (approximately 2-week intervals). Nutrients or manure may be added as supplements. Occasional irrigation may be required to maintain soil moisture • Construction of leachate collection system will minimize chance for off-site migration	• No control of volatile emissions • Land treatment is defined as a form of land disposal under RCRA 3004(b). If "placement" invokes land ban requirements, a no-migration petition is required
Contained Solid Phase	• Treatment occurs in an enclosure which allows more process control • Treatment in a device which is defined as a "tank" under RCRA is viable means of achieving land ban requirements • Testing is underway on PCB waste in rotating drums which allow control of oxygen levels • No secondary containment is required if the waste does not contain free liquids	• More costly than land treatment (farming) due to extra expense required to satisfy tank standards and provide more process control (e.g., aeration)
In Situ	• Under favorable conditions, this will be the lowest cost bioremediation technology	• Applications limited to favorable site conditions which require soils that are sandy and highly permeable (K greater than 10^{-3} m/s)

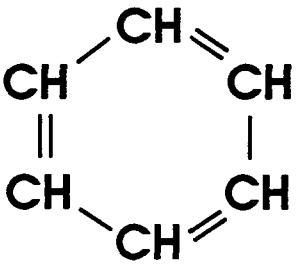
SECTION 7.8 EXHIBIT 2 - STRENGTHS AND LIMITATIONS OF BIOREMEDIATION TECHNIQUES

Technique	Strengths	Limitations
In Situ (continued)	• Ongoing testing concerns degradation of chlorinated compounds (TCE) using methane oxidizing bacteria (methanotrophs) • Although the reaction rate is lowest, a large volume of soil may be treated at once • Research in anerobic processes for reductive dechlorination shows promising results	• Extensive treatability studies and site characterization is required. Relevant physical and chemical parameters include pH, redox conditions, temperature, TOC, Fe and Mn concentrations, heavy metals, and nutrients (nitrogen and phosphorous) dissolved oxygen, carbon dioxide, nitrate, and sulfate • The technology has only been applied to hydrocarbon contamination; usually petroleum related • Proper design and operation is necessary to avoid ground-water contamination • The precise fate of degraded hydrocarbons, such as gasoline, is not yet known • Most difficult process to conclusively monitor cleanup efficiency since no mixing takes place, i.e., it may be difficult to get characteristic or representative samples if soil concentrations vary widely. • Water recirculation may be limited by biofouling or biological growth which reduces permeability • Difficulties may arise in the dissemination of oxygen and nutrients in low permeability or highly heterogeneous regimes • Some states may not allow reinjection of treated ground water; therefore, amendments must be delivered to the injection point in clean water • With the current state-of-the-art, in situ bioremediation is relatively ineffective for LNAPL and DNAPL

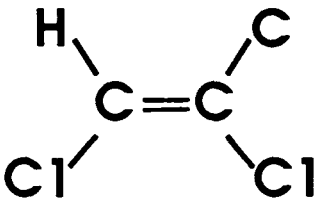
Degradation Potential



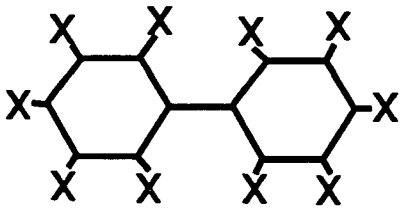
Octane



Benzene

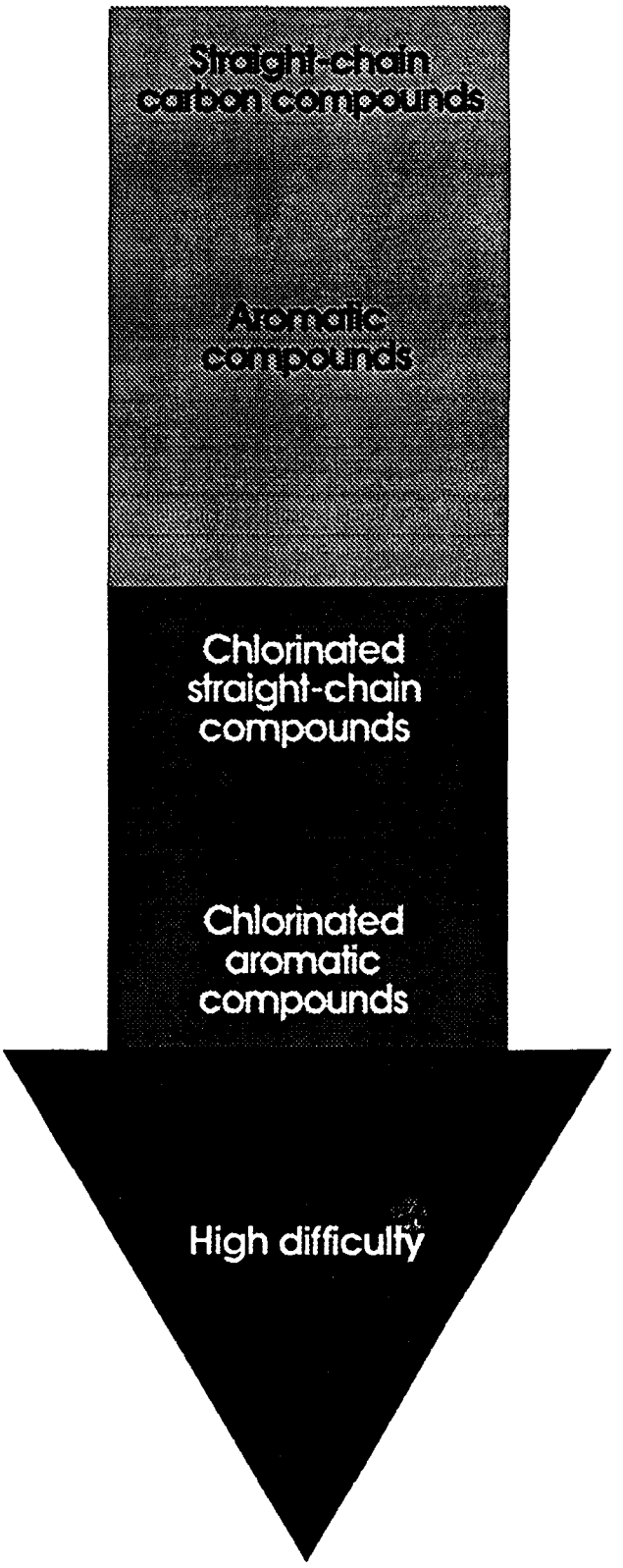


Trichloroethylene
(TCE)



X=H or Cl

PCB



Technology Transfer February 1989 CERI-89-11

EPA

Bioremediation of Hazardous Waste Sites Workshop

Speaker Slide Copies and Supporting Information

Waste Type: Soils and Sludges
Technology: Biodegradation

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Variable waste composition	Inconsistent biodegradation caused by variation in biological activity.	Waste composition
Water solubility	Contaminants with low solubility are harder to diodegrade.	Solubility
Biodegradability	Low biodegradability inhibits process.	Chemical constituents, bench-scale testing
Temperature outside 59-158°F (15-70°C) range	Larger, more diverse microbial population present in this range.	Temperature monitoring
Nutrient deficiency	Lack of adequate nutrients for biological activity (although nutrient supplements may be added).	C/N/P ratio
Oxygen deficiency	Lack of oxygen is rate limiting.	Oxygen monitoring
Moisture content	A moisture content of greater than 79% affects bacterial activity and availability of oxygen. A moisture content below 40% severely inhibits bacterial activity.	Ratio of air to water in interstices, porosity of composting mass
pH outside 4.5-8.5 range	Inhibition of biological activity	Sludge pH testing
Microbial population	If indigenous microorganisms not present, cultured strains can be added.	Culture test
Water and air emissions and discharges (composting only)	Potential environmental and/or health impacts (control achieved through air scrubbing, carbon filtration, forced aeration, cement liner).	Concentrations of contaminants
Compaction of compost (composting only)	Particles tend to coalesce and form an amorphous mass that is not easily maintained in an aerobic environment (wood chips or shredded tires may be added as bulking agents).	Determine integrity, physical nature of material

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

Waste Type: Soils and Sludges
Technology: Biodegradation (continued)

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Nonuniform particle (composting only)	Waste mixtures must be of uniform particle size.	Particle size distribution
Presence of elevated levels of: • Heavy metals • Highly chlorinated organics • Some pesticides, herbicides • Inorganic salts	Can be highly toxic to microorganicsms.	Analysis for priority pollutant

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

Waste Type: Soils and Sludges
Technology: In Situ Biodegradation

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Variable waste composition	Inconsistent biodegradation caused by variation in biological activity.	Waste composition
Water solubility	Contaminants with low solubility are harder to biodegrade.	Solubility
Biodegradability	Low biodegradability inhibits process.	Chemical constituents, presence of metals/ salts, bench-scale testing
Temperature outside 77-158°F (25-70°C) range	Larger, more diverse microbial population present in this range.	Temperature monitoring
Nutrient deficiency	Lack of adequate nutrients for biological activity (although nutrient supplements may be added).	C/N/S ratio
Oxygen deficiency	Oxygen depletion slows down the process.	Oxygen monitoring
Moisture content	A moisture content of greater than 79% affects bacterial activity and availability of oxygen. A moisture content below 40% severely inhibits bacterial activity.	Ratio of air to water in interstices, porosity of composting mass
pH oustide 4.5-7.5 range	Inhibition of biological activity.	Sludge pH testing
Microbial population	If indigenous microorganisms not present, cultured strains can be added.	Culture test
Presence of elevated levels of: • Heavy metals • Highly chlorinated organics • Some pesticides, herbicides • Inorganic salts	Can be highly toxic to microorganisms.	Analysis for contaminants

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

EXHIBIT 5 - WASTE CHARACTERISTIC TABLES (continued)

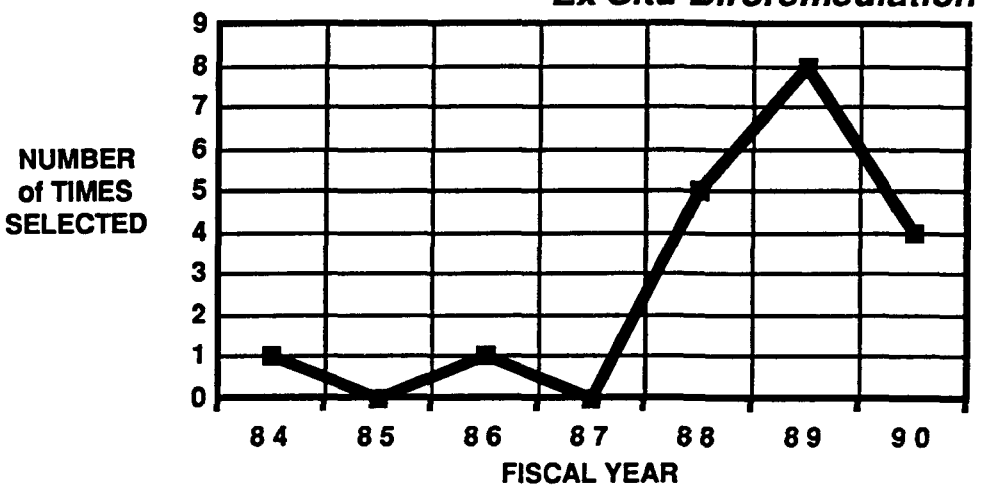
Waste Type: Soils and Sludges
Technology: In Situ Biodegradation (continued)

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Unfavorable soil characteristics		
• Low permeability	Hinders movement of water and nutrients through contaminated area.	Percolation testing
• Variable soil conditions	Inconsistent biodegradation due to variation in biological activity.	Soil mapping
• Low soil pH (<5.5)	Inhibition of biological activity.	Soil pH testing
• Low soil organic content	Lack of organic substrate for biological growth.	Soil humus content
• Low moisture content (<10%)	Subsurface biological growth requires adequate moisture.	Soil moisture content
Unfavorable site hydrology	Groundwater flow patterns must permit pumping for extraction and reinjection.	Site hydrogeology must be well defined.
Unfavorable groundwater quality parameters		
• Low dissolved oxygen	Oxygen necessary for biological growth.	Dissolved oxygen in ground water, determine amount of hydrogen peroxide needed to satisfy oxygen demand
• Low pH, alkalinity	Inhibition of biological activity.	pH and alkalinity of ground water

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

Selection Frequency*

Ex Situ Biroremediation

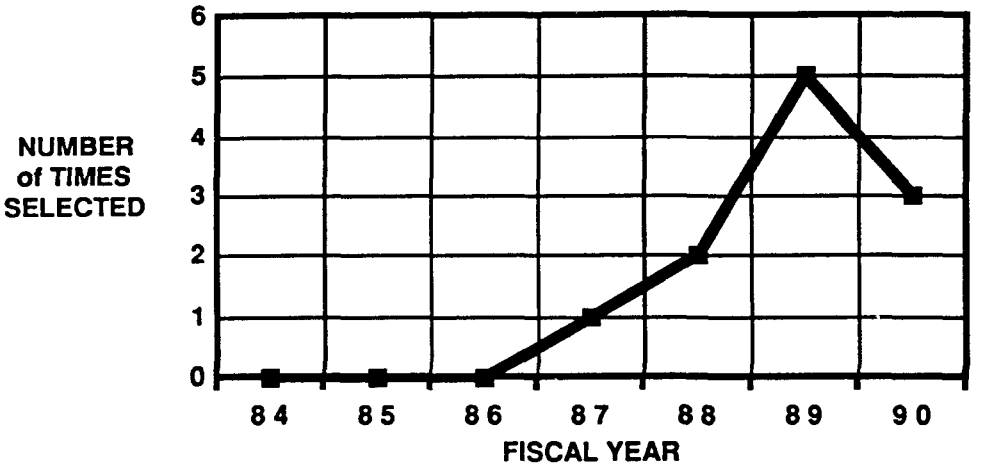


* *Data derived from 1982 - 1990 Records of Decision (RODs) and anticipated design and construction activities.*

September 1991

Selection Frequency*

In Situ Bioremediation



* *Data derived from 1982 - 1990 Records of Decision (RODs) and anticipated design and construction activities.*

September 1991

7.12 EXHIBIT 6 - DATA FROM THE SEMI-ANNUAL STATUS REPORT
(continued)

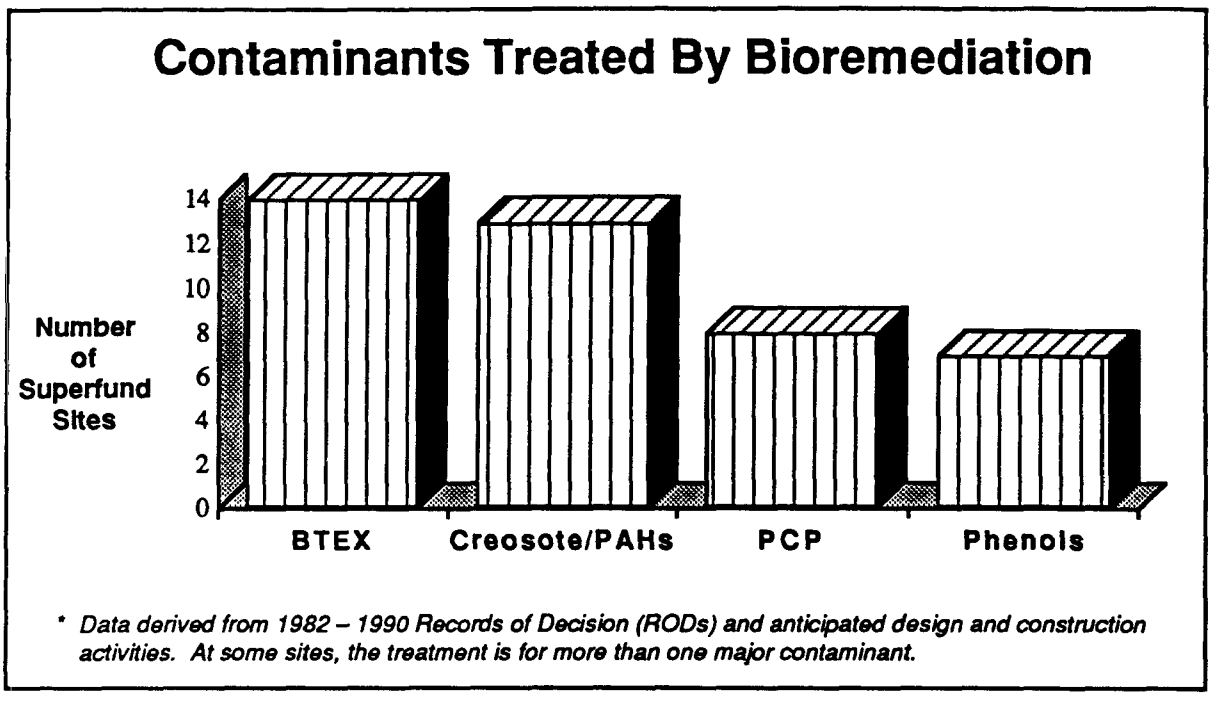


EXHIBIT 7 - INNOVATIVE TREATMENT TECHNOLOGIES: SEMI-ANNUAL STATUS REPORT

DETAILED SITE INFORMATION BY TREATMENT TECHNOLOGY

September, 1991

Bioremediation (Ex situ)

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
1	Iron Horse Park, MA* (09/15/88)	Land treatment	Industrial Complex & Railyard Wastes	Sludge, Soil (28,000 cy combined)	Petroleum Hydrocarbons, VOCs (BTEX), and PAHs	In design; Design completion planned Summer '91	PRP Lead; ENSR, Consulting	Don McElroy 617-223-5518 FTS 833-1518
3	L.A. Clarke & Sons, VA* (03/31/88) Also see In situ Flushing	On-site bioremediation - type to be determined	Wood Preserving	Soil (73,700 cy), Sediments (45,300 cy)	Creosote, PAHs, and VOCs (Benzene)	Pilot study planned 1992; Design completion planned Winter '93	PRP Lead	Gene Wingert 215-597-1727 FTS 597-1727
3	Ordnance Works Disposal, WV (09/29/89)	Land treatment	Chemical Formulation	Soil (13,460 cy)	Carcinogenic PAHs	In design; Design completion planned Summer '92	PRP Lead	Drew Lausch 215-597-1286 FTS 597-1286
4	American Creosote Works, FL* (09/28/89) Also see Soil Washing	Slurry-phase bioremediation for fines from soil washing	Wood Preserving	Fines from 21,000 cy of soil	Creosote, PAHs, SVOCs (PCP), and Dioxins	In design; undergoing additional treatability testing	Fund Lead	Madelaine Streng 404-347-2643 FTS 257-2643
4	Brown Wood Preserving, FL* (04/08/88)	Land treatment	Wood Preserving	Soil (7,500 cy)	Creosote and PAHs	Project completed; Operational 10/88 - 8/91	PRP Lead; Remediation Technology, Inc.	Martha Berry 404-347-2643 FTS 257-2643
4	Coleman Evans Wood Preserving, FL* (9/26/90) Also see Soil Washing	Slurry-phase bioremediation of fines from soil washing	Wood Preserving	Fines from 27,000 cy of soil	SVOCs (PCP), Dioxin	Pilot study planned; Design completion planned Spring '92	Fund Lead	Tony Best 404-347-2643 FTS 257-2643
4	Dubose Oil Products, FL (03/29/90)	Solid-phase bioremediation	Oil Recycling	Soil (15,000 cy)	PCP	Predesign; Pilot studies planned	PRP Lead	Mike McKibben 404-347-2643 FTS-257-2643

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Bioremediation (Ex situ)

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
4	Southeastern Wood Preserving, MS (Emergency Response -AM signed 9/30/90) Also see Soil Washing	Slurry-phase bioremediation of fines from soil washing	Wood Preserving	4,000 cy of fines from soil washing	SVOCs (PCP), PAHs, and Creosote	Project Ongoing; Demonstration on 700 cy 2/91 - 8/91; Full-scale cleanup began 8/91	Fund Lead OHM Remediation Services Corp.	Don Rieger 404-347-3931 FTS 257-3931
5	Burlington Northern (Railroad Tie Treating Plant), MN* (06/04/86)	Land treatment	Wood Preserving	Soil (9,500 cy), Sludge (9,600 cy)	Creosote, PAHs, and SVOCs (Phenols)	Operational; Expected completion 1993	PRP Lead; Remediation Technologies, Inc.	Amy Blumberg 312-353-9306 FTS 886-9306 Todd Goeks (MN) 612-296-7710 Rich Truax (Retec) 303-493-3700
5	Cliff/Dow Dump, MI* (09/27/89) Also see Bioremediation (In situ)	Excavation/on-site bioremediation - type to be determined	Waste Disposal for Charcoal Manufacturing Plant	Soil (9,200 cy)	Tar, PAHs, VOCs (BTX and PCE), and SVOCs (Phenol)	Predesign	PRP Lead	Lida Tan 312-886-1842 FTS 886-1842
5	Galesburg/Koppers, IL (06/30/89)	Land treatment	Wood Preserving	Soil (15,200 cy)	Creosote, PAH, Phenols, and PCP	Predesign	PRP Lead/State Enforcement; Remediation Technologies, Inc.	Brad Bradley 312-886-4742 FTS 886-4742 Steve Davis (IL) 217-785-3913
5	Joslyn Manufacturing and Supply Co., MN (ROD Planned)	Land treatment	Wood Preserving	Soil (75,000 cy)	PAHs and SVOCs (PCP)	Operational since 8/89; scheduled completion end of 1991	PRP Lead/State Enforcement; ECOVA Corp.	Kevin Turner 312-886-4444 FTS 886-4444 Cliff Twaroski (MN) 612-296-7827
5	Moss-American, WI (09/27/90) Also see Soil Washing	Slurry-phase of fines from soil washing and sediments	Wood Preserving	Sediments (5,200 cy), Fines from soil (80,000 cy)	PAHs	Predesign; Design completion planned winter '93	PRP Lead; Weston, Inc.	Betty Lavis 312-886-4784 FTS 886-4784

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Bioremediation (Ex situ)

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
6	*Old Inger Oil Refinery, LA** (09/25/84)	Land treatment	Oil Refining & Waste Oil Reclamation	Soil (approx. 100,000 cy), Waste oil and sludge (3,964 cy combined)	Petroleum Hydrocarbons and VOCs (Benzene, Ethylbenzene),	Installation underway; operation to be bid Winter '91/'92	State Lead/Fund Financed; Westinghouse Haztech (Construction)	Paul Sieminski 214-655-6710 FTS 255-6710 Sandra Greenwich (LA) 504-765-0487
6	Atchison/Santa Fe/ Clovis, NM (09/23/88) Also see Bioremediation (In situ)	Land treatment of soils/sludge	Railyard Wastes (Industrial Wastewater)	Soil, Sludges (28,599 cy combined)	Phenols, Petroleum Hydrocarbons, and Diesel Fuel	In design; Design completion planned Spring '92	PRP Lead; Radian Corp.	Susan Webster 214-655-6730 FTS 255-6730
6	North Cavalcade Street, TX* (06/28/88)	Modified land treatment	Wood Preserving	Soil (22,300 cy)	Creosote, PAHs, and VOCs (BTX)	In design; Design completion planned Fall '92	State Lead/Fund Financed	Deborah Griswold 214-655-6715 FTS 255-6715 Lewis Rogers (TX) 512-463-8188
6	Sheridan Disposal Services, TX* (12/29/88)	Slurry-phase bioremediation	Commercial Waste Disposal	Soil (13,000 cy), Sludge (31,000 cy), Oil/emulsion (300 cy)	VOCs (Benzene, Toluene) and SVOCs (Phenols)	Predesign; pilot study underway; design completion planned Summer '93	PRP Lead	Ruth Israeli 214-655-6735 FTS 255-6735
7	Vogel Paint & Wax, IA* (09/25/89)	Land treatment	Paint Manufacturing Wastes	Soil (10,000 - 40,000 cy)	VOCs (Methyl Ethyl Ketone and BTX)	In design; Design completion planned Summer '91	PRP Lead/ State Enforcement; Geoteck Engineering and Testing Services, Inc.	Steve Jones 913-551-7755 FTS 276-7755 Bob Drustrup (IA) 515-281-8900
7	Scott Lumber, MO (Emergency Response -AM signed 7/10/87)	Land treatment	Wood preserving	Soil (16,000 tons)	PAHs and Benzo(a)pyrene	Ongoing; Process started in 1987	Fund Lead; Remediation Technologies, Inc.	Bruce Morrison 913-551-5014 FTS 276-5014
8	Burlington Northern (Somers Plant), MT* (09/27/89) Also see Bioremediation (In situ)	Land treatment	Wood Preserving	Soil, Sediments (11,700 cy combined)	Creosote, PAHs, and SVOCs (Phenols)	In design; Design completion planned Fall '92	PRP Lead; Remediation Technologies, Inc.	Jim Harris 406-449-5414 FTS 585-5414

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Bioremediation (Ex situ)

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
8	Libby Ground Water Contamination, MT* (12/30/88) Also see Bioremediation (In situ)	Land treatment	Wood Preserving	Soil (45,000 cy)	Creosote, SVOCs (PCP), VOCs (Benzene), and PAHs	Operational; 2-year, 1-acre demonstration completed 8/89; full-scale treatment to be completed in 1999	PRP Lead	Julie Dalsoglio 406-449-5414 FTS 585-5414 Bert Bledsoe (RSKERL) 405-332-2313 FTS 743-2313
9	J.H. Baxter, CA* (09/27/90)	Solid-phase bioremediation	Wood Preserving	Soil (10,000 cy)	SVOCs (PCP), PAHs, and Dioxins	In design; Design completion planned Summer '92	Fund Lead	Mary Masters 415-744-2370 FTS 484-2370
9	Poly-Carb, NV (Emergency Response -AM signed 5/14/87) Also see In situ Flushing	Land treatment in conjunction with soil flushing	Commercial Waste Management	Soil (1,500 cy)	Phenols and Cresol	Process completed; Operational 7/87 - 8/88	Fund Lead; Crosby and Overton, EMI (subcontractors to Reidel Environmental Services)	Bob Mandel 415-744-2290 FTS 484-2290

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Bioremediation (In situ)

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
2	FAA Technical Center, NJ - Area D (09/26/89) Also see Vacuum Extraction	In situ gw bioremediation (Area D only)	Jet Fuel Tank Farm	gw	VOCs (BTEX)	In design; Design completion planned 9/91	PRP Lead	Carla Struble 212-264-4595 FTS 264-4595 Keith Buch (FAA) 609-484-6644
4	Cabot/Koppers, FL (09/27/90) Also see Soil Washing	In situ soil bioremediation	Wood treating and pine tar distillation facility	Soil (5,000 cy)	SVOCs [Bis(2-ethyl-hexyl)phthalate, 2,4-Dimethylphenol, 2,4-Dinitrotoluene, Di-n-octylphthalate, Penta-chlorophenol, Phenol], PAHs	In design; Treatability study planned Design completion planned Spring '93	PRP Lead	Martha Berry 404-347-2643 FTS-257-2643
5	Cliff/Dow Dump, MI* (09/27/89) Also see Bioremediation (Ex situ)	In situ soil and gw bioremediation	Waste Disposal for Charcoal Manufacturing Plant	gw, soil	VOCs (BTX), PAHs, and SVOCs (Phenols)	Predesign	PRP Lead	Lida Tan 312-886-1842 FTS 886-1842
5	Onalaska Municipal Landfill, WI (08/14/90)	In situ soil bioremediation	Municipal Landfill	Soil (≈20,000 cy; to 15' depth)	VOCs (TCE, BTEX, DCE, TCA, DCA) and SVOCs (Naphthalene)	In design; bench study planned Fall '91; design completion planned Summer '92	Fund Lead	Kevin Adler 312-886-7078 FTS 886-7078
5	Seymour Recycling, IN* (09/30/87) Also see Vacuum Extraction	In situ soil bioremediation	Chemical Waste Management and Incineration	Soil	Petroleum Hydrocarbons, BTEX, and various SVOCs	Remedial action completed (small component of total remedy)	PRP Lead; ABB Environmental Services (subcontractor to Geraghty & Miller)	Jeff Gore 312-886-6552 FTS 886-6552
6	Atchison/Santa Fe/ Clovis, NM (09/23/88) Also see Bioremediation (Ex situ)	In situ soil bioremediation	Railyard Wastes (Industrial Wastewater)	Soil, Sludges (28,599 cy combined)	Phenols, Petroleum Hydrocarbons, and Diesel Fuel	Construction underway; startup planned Oct. '91.	PRP Lead; Radian Corp.	Susan Webster 214-655-6730 FTS 255-6730

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Bioremediation (In situ)

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
6	French Limited, TX (03/24/88)	In situ lagoon bioremediation	Petrochemical	Sludge, Sediments (70,100 cy)	VOCs (BTEX), PAHs, Petroleum Hydrocarbons, and PCBs	In design	PRP Lead	Judith Black 214-655-6735 FTS 255-6735
8	Burlington Northern (Somers Plant), MT* (09/27/89)	In situ gw bioremediation	Wood Preserving	gw	Creosote, PAHs, and SVOCs (Phenol)	In design; Design completion planned Fall '92	PRP Lead; Remediation Technologies, Inc.	Jim Harris 406-449-5414 FTS 585-5414
8	Libby Ground Water Contamination, MT* (12/30/88)	In situ gw bioremediation	Wood Preserving	gw	Creosote, VOCs (Benzene), PAHs, SVOCs (PCP), and Oil	In design; Phase 1 design completion planned Summer '91; Phase 2 design completion planned Spring '93	PRP Lead	Julie Dalsoglio 406-449-5414 FTS 585-5414 Bert Bledsoe (RSKERL) 405-332-2313 FTS 743-2313
9	Gila River Indian Reservation, AZ (Emergency Response -AM signed 7/31/84) Also see Chemical Treatment	In situ anaerobic soil biodegradation (preceded by chemical treatment)	Airfield with buried drums of pesticides	Soil (3,200 cy)	Toxaphene	Project completed; Operational 6/85 - 10/85	Fund Lead	Richard Martin 414-744-2288 FTS 484-2288
9	Koppers (Oroville Plant), CA (09/13/89) Also see Soil Washing	In situ soil bioremediation	Wood Preserving	Soil (110,000 cy)	SVOCs (PCP), Creosote, PAHs, VOCs (BTX), Dioxin	In design; Design completion planned Summer '92	PRP Lead	Fred Schauffler 415-744-2365 FTS 484-2365
9	Roseville Drums, CA (Emergency Response -AM signed 3/3/88)	In situ soil bioremediation	Midnight dump on dirt road in undeveloped area	Soil (14 cy)	Dichlorobenzene and Phenols	Project completed; Operational 2/88 - 11/88	Fund Lead	Brad Shipley 415-744-2287 FTS 484-2287
9	Solvent Service, CA (09/27/90) Also see Vacuum Extraction	In situ gw bioremediation	Solvent operation	gw	VOCs (Total, Acetone, Ethylbenzenes, TCA, and Xylenes) and SVOCs (Dichlorobenzene)	Operational	State Lead site under RCRA authority	Marie Lacey 415-744-2234 FTS 484-2234

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

United States Environmental Protection Agency	Office of Emergency and Remedial Response Washington, DC 20460	Office of Research and Development Cincinnati, OH 45268
Superfund	EPA/540/2-90/016	September 1990

Engineering Bulletin

EPA Slurry Biodegradation

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants and contaminants as a principal element." The Engineering Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial investigation scoping needs. Addenda will be issued periodically to update the original bulletins.

Abstract

In a slurry biodegradation system, an aqueous slurry is created by combining soil or sludge with water. This slurry is then biodegraded aerobically using a self-contained reactor or in a lined lagoon. Thus, slurry biodegradation can be compared to an activated sludge process or an aerated lagoon, depending on the case.

Slurry biodegradation is one of the biodegradation methods for treating high concentrations (up to 250,00 mg/kg) of soluble organic contaminants in soils and sludges. There are two main objectives for using this technology: to destroy the organic contaminant and, equally important, to reduce the volume of contaminated material. Slurry biodegradation is not effective in treating inorganics, including heavy metals. This technology is in developmental stages but appears to be a promising technology for cost-effective treatment of hazardous waste.

Slurry biodegradation can be the sole treatment technology in a complete cleanup system, or it can be used in conjunction with other biological, chemical, and physical treatment. This technology was selected as a component of the remedy for polychlorinated biphenyl (PCB)-contaminated oils at the General Motors Superfund site at Massena, New York, [11, p. 2]* but has not been a preferred alternative in any record of decision [6, p. 6]. It may be demonstrated in the Superfund Innovative Technology Evaluation (SITE) program. Commercial-scale units are in operation. Vendors should be contacted to determine the availability of a unit for a particular site. This bulletin provides information on the technology applicability, the types of residuals produced, the latest performance data, site requirements, the status of the technology, and sources for further information.

Technology Applicability

Biodegradation is a process that is considered to have enormous potential to reduce hazardous contaminants in a cost-effective manner. Biodegradation is not a feasible treatment method for all sites. Each vendor's process may be capable of treating only some contaminants. Treatability tests to determine the biodegradability of the contaminants and the solids/liquid separation that occurs at the end of the process are very important.

Slurry biodegradation has been shown to be effective in treating highly contaminated soils and sludges that have contaminant concentrations ranging from 2,500 mg/kg to 250,000 mg/kg. It has the potential to treat a wide range of organic contaminants such as pesticides, fuels, creosote, pentachlorophenol (PCP), PCBs, and some halogenated volatile organics. It is expected to treat coal tars, refinery wastes, hydrocarbons, wood-preserving wastes, and organic and chlorinated organic sludges. The presence of heavy metals and chlorides may inhibit the microbial metabolism and require pretreatment. Listed Resource Conservation and Recovery Act (RCRA) wastes it has treated are shown in Table 1[10, p. 106].

*[Reference number, page number]

Table 1
RCRA-Listed Hazardous Wastes

Wood Treating Wastes	K001
Dissolved Air Floatation (DAF) Float	K048
Slop Oil Emulsion Solids	K049
American Petroleum Institute (API) Separator Sludge	K051

The effectiveness of this slurry biodegradation on general contaminant groups for various matrices is shown in Table 2 [12, p. 13]. Examples of constituents within contaminant groups are provided in Reference 12, "Technology Screening Guide for Treatment of CERCLA Soils and Sludges." This table is based on current available information or professional judgment when no information was available. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the treatment efficiency achieved will be acceptable at other sites. For the ratings used for this table, demonstrated biodegradability means that, at some scale, treatability was tested to show that, for that particular contaminant and matrix, the technology was effective. The ratings of potential biodegradability and no expected biodegradability are based upon expert judgment. Where potential biodegradability is indicated, the technology is believed capable of successfully treating the contaminant group. When the technology is not applicable or will probably not work for a particular contaminant group, a no-expected-biodegradability rating is given. Another source of general observations and average removal efficiencies for different treatability groups is contained in the Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions," (OSWER Directive 9347.3-06FS [10], and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions," (OSWER Directive 9347.3-07FS [9].

Limitations

The various characteristics limiting the process feasibility, the possible reasons for these, and actions to minimize impacts of these limitations are listed in Table 3 [11, p. 2]. Some of these actions could be a part of the pretreatment process. The variation of these characteristics in a particular hardware design, operation, and/or configuration for a specific site will largely determine the viability of the technology and cost-effectiveness of the process as a whole.

Table 2
Degradability Using Slurry Biodegradation Treatment on General Contaminant Groups for Soils, Sediments, and Sludges

	Contaminant Groups	Biodegradability All Matrices
Organic	Halogenated volatiles	▼
	Halogenated semivolatiles	■
	Nonhalogenated volatiles	▼
	Nonhalogenated semivolatiles	■
	PCBs	▼
	Pesticides	■
	Dioxins/Furans	❑
	Organic cyanides	▼
	Organic corrosives	❑
Inorganic	Volatile metals	❑
	Nonvolatile metals	❑
	Asbestos	❑
	Radioactive materials	❑
	Inorganic corrosives	❑
	Inorganic cyanides	▼
Reactive	Oxidizers	❑
	Reducers	❑

■ Demonstrated Effectiveness: Successful treatability test at some scale completed
▼ Potential Effectiveness: Expert opinion that technology will work
❑ No Expected Effectiveness: Expert opinion that technology will not work

Technology Description

Figure 1 is a schematic of a slurry biodegradation process.

Waste preparation (1) includes excavation and/or moving the waste material to the process where it is normally screened to remove debris and large objects. Particle size reduction, water addition, and pH and temperature adjustment are other important waste preparation steps that may be required to achieve the optimum inlet feed characteristics for maximum contaminant reduction. The desired inlet feed characteristics [6, p. 14] are:

Organics:	.025-25%	by weight	Temperature: 15-35°C
Solids:	10-40%	by weight	pH: 4.5-8.8
Water:	60-90%	by weight	
Solids particle size:		Less than 1/4"	

After appropriate pretreatment, the wastes are suspended in a slurry form and mixed in a tank (2) to maximize the mass transfer rates and contact between contaminants and microorganisms capable of degrading those contaminants. Aerobic treatment in batch mode has been the most common mode of operation. This process can be performed in contained reactors (3) or in lined lagoons [7, p. 9]. In the latter case, synthetic liners have to be placed in existing unlined lagoons, complicating the operation and maintenance of the system. In this case, excavation of a new lagoon or above-ground tank reactors should be considered. Aeration is provided by floating or submerged aerators or by compressors and spargers. Mixing is provided by aeration alone or by aeration and mechanical mixing. Nutrients and neutralizing agents are supplied to relieve any chemical limitations to microbial activity. Other materials, such as surfactants, dispersants, and compounds supporting growth and inducing degradation of contaminant compounds, can be used to improve the materials' handling characteristics or increase substrate availability for degradation [8, p. 5]. Microorganisms may be added initially to seed the bioreactor or added continuously to maintain the correct concentration of biomass. The residence time in the bioreactor varies with the soil or sludge matrix; physical/chemical nature of the contaminant, including concentration; and the biodegradability of the contaminants. Once biodegradation of the contaminants is completed, the treated slurry is sent to a separation/dewatering system (4). A clarifier for gravity separation, or any standard dewatering equipment, can be used to separate the solid phase and the aqueous phase of the slurry.

Process Residuals

There are three main waste streams generated in the slurry biodegradation system: the treated solids (sludge or soil), the process water, and possible air emissions. The solids are dewatered and may be further treated if they still contain organic contaminants. If the solids are contaminated with inorganics and/or heavy metals, they can be stabilized before disposal. The process water can be treated in an onsite treatment system prior to discharge, or some of it (as high as 90 percent by weight of solids) is usually recycled to the front end of the system for slurrying. Air emissions are possible during operation of the system (e.g., benzene, toluene, xylene [BTX] compounds); hence, depending on the waste characteristics, air pollution control, such as activated carbon, may be necessary [4, p. 29].

Site Requirements

Slurry biodegradation tank reactors are generally transported by trailer. Therefore, adequate access roads are required to get the unit to the site. Commercial units require a setup area of 0.5-1 acre per million gallons of reactor volume.

Standard 440V three-phase electrical service is required. Compressed air must be available. Water needs at the site can be high if the waste matrix must be made into slurry form. Contaminated soils or other waste materials are hazardous and their handling requires that a site safety plan be developed to provide for personnel protection and special handling measures.

Climate can influence site requirements by necessitating covers over tanks to protect against heavy rainfall or cold for long residence times.

Large quantities of wastewater that results from dewatering the slurried soil or that is released from a sludge may need to be stored prior to discharge to allow time for analytical tests to verify that the standard for the site has been met. A place to discharge this wastewater must be available.

Onsite analytical equipment for conducting dissolved oxygen, ammonia, phosphorus, pH, and microbial activity are needed for process control. High-performance liquid chromatographic and/or gas chromatographic equipment is desirable for monitoring organic biodegradation.

Performance Data

Performance results on slurry biodegradation systems are provided based on the information supplied by various vendors. The quality assurance for these results has not been evaluated. In most of the performances, the cleanup criteria were based on the requirements of the client; therefore, the data do not necessarily reflect the maximum degree of treatment possible.

Remediation Technologies, Inc.'s (ReTeC) full-scale slurry biodegradation system (using a lined lagoon) was used to treat wood preserving sludges (K0001) at a site in Sweetwater, Tennessee, and met the closure criteria for treatment of these sludges. The system achieved greater than 99 percent removal efficiency and over 99 percent reduction in volume attained for PCP and polynuclear aromatic hydrocarbons (PAHs) (Table 4 and Table 5).

Figure 1
Slurry Biodegradation Process

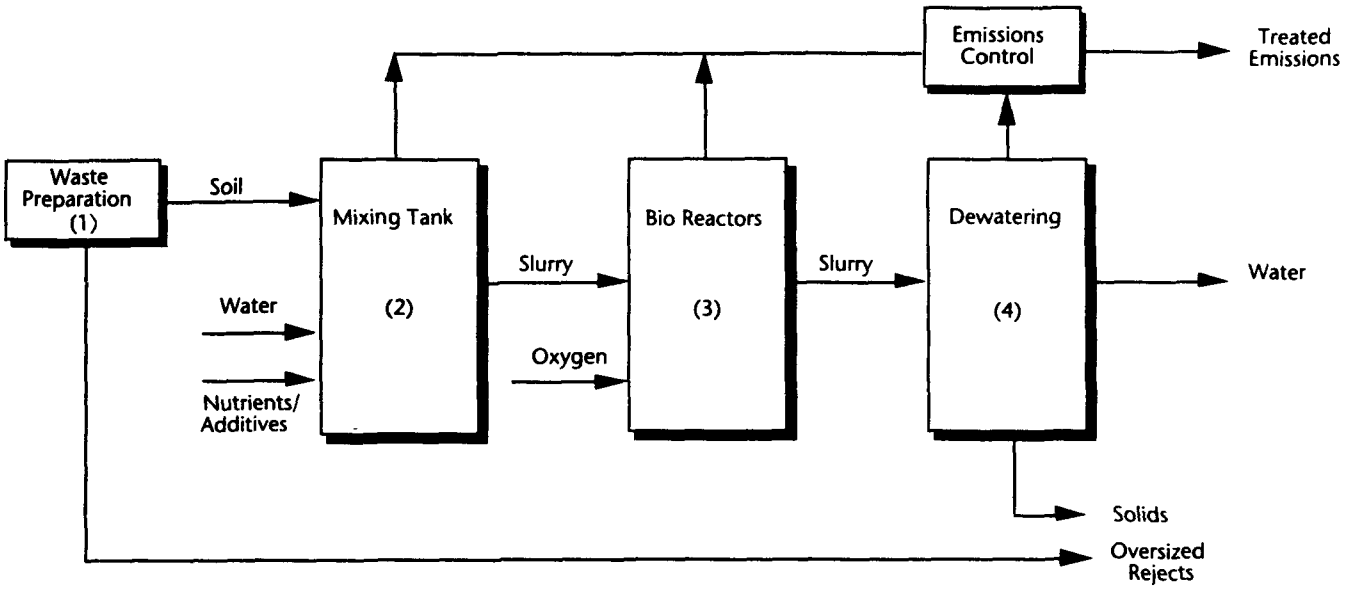


Table 3
Characteristics Limiting the Slurry Biodegradation Process

CHARACTERISTICS LIMITING THE PROCESS FEASIBILITY	REASONS FOR POTENTIAL IMPACT	ACTIONS TO MINIMIZE IMPACTS
Variable waste composition	Inconsistent biodegradation caused by variation in biological activity	Dilution of waste stream. Increase mixing
Nonuniform particle size	Minimize the contact with microorganisms	Physical separation
Water solubility	Contaminants with low solubility are harder to biodegrade	Addition of surfactants or other emulsifiers
Biodegradability	Low rate of destruction inhibits process	Addition of microbial culture capable of degrading particularly difficult compounds or longer residence time
Temperature outside 15-35°C range	Less microbial activity outside this range	Temperature monitoring and adjustments
Nutrient deficiency	Lack of adequate nutrients for biological activity	Nutrient monitoring; adjustment of the carbon/nitrogen/phosphorus ratio
Oxygen deficiency	Lack of oxygen is rate limiting	Oxygen monitoring and adjustments
Insufficient Mixing	Inadequate microbes/solids/organics contact	Optimize mixing characteristics
pH outside 4.5 - 8.8 range	Inhibition of biological activity	Sludge pH monitoring. Addition of acidic or alkaline compounds
Microbial population	Insufficient population results in low biodegradation rates	Culture test, addition of culture strains
Water and air emissions discharges	Potential environmental and/or health impacts	Post-treatment processes (e.g., air scrubbing, carbon filtration)
Presence of elevated, dissolved levels of: • Heavy metals • Highly chlorinated organics • Some pesticides, herbicides • Inorganic salts	Can be highly toxic to microorganisms	Pretreatment processes to reduce the concentration of toxic compounds in the constituents in the reactor to nontoxic range

Table 4
Results Showing Reduction in Concentration for Wood Preserving Wastes

Compounds	Initital Concentration		Final Concentration		Percent Removal	
	Solids (mg/kg)	Slurry (mg/kg)	Solids (mg/kg)	Slurry (mg/kg)	Solids (mg/kg)	Slurry (mg/kg)
Phenol	14.6	1.4	0.7	<0.1	95.2*	92.8
Pentachlorophenol	687	64	12.3	0.8	98.2	92.8
Naphthalene	3,670	343	23	1.6	99.3*	99.5*
Phenanthrene & Anthracene	30,700	2,870	200	13.7	99.3	99.5
Fluoranthene	5,470	511	67	4.6	98.8	99.1
Carbazole	1,490	139	4.9	0.3	99.7	99.8

*May be due to combined effect of Volatilization and Biodegradation. [Source: ReTec, 50,000 gal. reactor]

Table 5
Results Showing Reduction in Volume For Wood Preserving Wastes

Compounds	Before Treatment (Total pounds)	After Treatment (Total pounds)	Percent Volume Reduction
Phenol	368	41.4	88.8*
Pentachlorophenol	141,650	193.0	99.9
Naphthalene	179,830	36.6	99.9*
Phenanthrene & Anthracene	2,018,060	303.1	99.9
Fluoranthene	190,440	341.7	99.8
Carbazole	114,260	93.7	99.9

*May be due to combined effect of Volatilization and Biodegradation. [Source: ReTec, 50,000 gal. reactor]

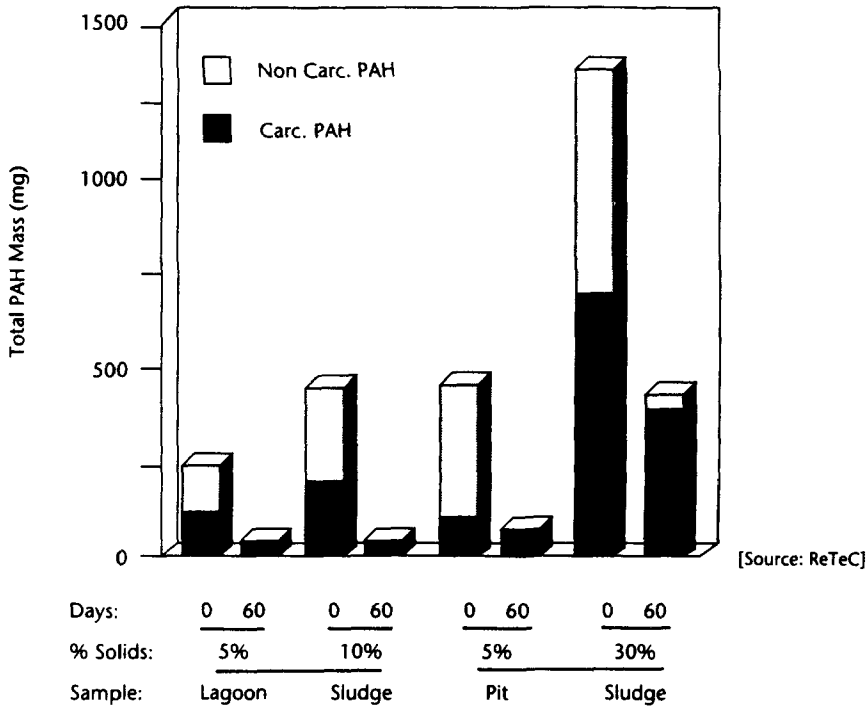
Data for one of these pilot-scale field demonstrations, which treated 72,000 gallons of oil refinery sludges, are shown in Figure 2 [8, p. 24]. In this study, the degradation of PAHs was relatively rapid and varied depending on the nature of the waste and loading rate. The losses of carcinogenic PAHs (principally the 5- and 6-ring PAHs) ranged from 30 to 80 percent over 2 months while virtually all of the noncarcinogenic PAHs were degraded. The total PAH reduction ranged from 70 to 95 percent with a reactor residence time of 60 days.

ECOVA's full-scale, mobile slurry biodegradation unit was used to treat more than 750 cubic yards of soil contaminated with 2,4-Dichlorophenoxy acetic acid (2,4-D) and 4-chloro-2-methyl-phenoxyacetic acid (MCPA) and other pesticides such as alachlor, trifluralin, and carbofuran. To reduce 2,4-D and MCPA levels from 800 ppm in soil and 400 ppm in slurry to less than 20 ppm for both in 13 days, 26,000-gallon bioreactors capable of handling approximately 60 cubic yards of soil were used. The residuals of the process were further treated through land application [3, p. 4]. Field application of the slurry biodegradation system designed by ECOVA to treat PCP-contaminated wastes has resulted in a 99-percent decrease in PCP concentrations (both in solid and aqueous phase) over a period of 24 days [3, p. 5].

Performance data for Environmental Remediation, Inc. (ERI) is available for the treatment of American Petroleum Institute (API) separator sludge and wood-processing wastes. Two lagoons containing an olefin sludge from an API separator were treated. In one lagoon, containing, 4,000 cubic yards of sludge, a degradation time of 21 days was required to achieve 68 percent volume reduction and 62 percent mass oil and grease reduction at an operating temperature of 18°C. In the second lagoon, containing 2,590 cubic yards of sludge, a treatment time of 61 days was required to achieve 61 percent sludge reduction and 87.3 percent mass oil and grease reduction at an operating temperature of 14°C [1, p. 367].

At another site, the total wood-preserving constituents were reduced to less than 50 ppm. Each batch process was

Figure 2
Pilot Scale Results on Oil Refinery Sludges



carried out with a residence time of 28 days in 24-foot-diameter, 20-foot-height tank reactors handling 40 cubic yards per batch [6]. The mean concentrations of K001 constituents before treatment and the corresponding concentrations after treatment, for both settled solids and supernatant, are provided in Table 6 [2, p. 11]. The supernatant was discharged to a local, publicly owned wastewater treatment works.

RCRA Land Disposal Restrictions (LDRs) that require treatment of wastes to best demonstrated available technology (BDAT) levels prior to land disposal may sometimes be determined to be applicable or relevant and appropriate requirements (ARARs) for CERCLA response actions. Slurry biodegradation can produce a treated waste that meets treatment levels set by BDAT, but may not reach these treatment levels in all cases. The ability to meet required treatment levels is dependent upon the specific waste constituents and the waste matrix. In cases where slurry biodegradaton does not meet these levels, it still may, in certain situations, be selected for use at the site if a treatability variance establishing alternative treatment levels is obtained. EPA has made the treatability variance process available in order to ensure that LDRs do not unnecessarily restrict the use of alternative and innovative treatment technologies. Treatability variances may be justified for handling complex soil and debris matrices. The following guides describe when and how to seek a treatability variance for soil and debris: Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions," (OSWER Directive 9347.3-06FS) [10] and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-07FS) [9]. Another approach could be to use other treatment techniques in series with slurry biodegradation to obtain desired treatment levels.

Technology Status

Biotrol, Inc. has a pilot-scale slurry bioreactor that consists of a feed storage tank, a reactor tank, and a dewatering system for the treated slurry. It was designed to treat the fine-particle slurry from its soil-washing system. Biotrol's process was included in the SITE program demonstration of its soil-washing system at the MacGillis and Gibbs wood-preserving site in New Brighton, Minnesota, during September and October of 1989. Performance data from the SITE demonstration are not currently available; the Demonstration and Applications Analysis Report is scheduled to be published in late1990.

Table 6
Results of Wood Preserving Waste Treatment

Wood Preserving Waste Constituents	Before treatment	After Treatment	
	In Soil (mg/kg)	In Settled Soil (mg/kg)	In Supernatant (mg/L)
2-Chlorophenol	1.89	<0.01	<0.01
Phenol	3.91	<0.01	<0.01
2,4-Dimethylphenol	7.73	<0.01	<0.01
2,4,6-Trichlorophenol	6.99	<0.01	<0.01
p-Chloro-m-cresol	118.62	<0.01	<0.01
Tetrachlorophenol	11.07	<0.02	<0.02
2,4-Dinitrophenol	4.77	<0.03	<0.03
Pentachlorophenol	420.59	3.1	<0.01
Naphthalene	1078.55	<0.01	0.04
Acenaphthylene	998.80	1.4	1.60
Phenanthrene + Anthracene	6832.07	3.8	3.00
Fluoranthene	1543.06	4.9	16.00
Chrysene + Benz(a)anthracene	519.32	1.4	8.20
Benzo(b)fluoranthene	519.32	<0.03	4.50
Benzo(a)pyrene	82.96	0.1	2.50
Indeno(1,2,3-cd)pyrene + Dibenz(a,h)anthracene	84.88	0.5	1.70
Carbazole	135.40	<0.05	1.70

[Source: Environmental Solutions, Inc.]

ECOVA Corporation has a full-scale mobile slurry biodegradation system. This system was demonstrated in the field on soils contaminated with pesticides and PCP. ECOVA has developed an innovative treatment approach that utilizes contaminated ground water on site as the make up water to prepare the slurry for the bioreactor.

ERI has developed a full-scale slurry biodegradation system. ERI's slurry biodegradation system was used to reduce sludge volumes and oil and grease content in two wastewater treatment lagoons at a major refinery outside of Houston, Texas, and to treat 3,000 cubic yards of wood-preserving waste (creosote-K001) over a total cleanup time of 18 months.

Environmental Solutions, Inc. reportedly has a full-scale slurry biodegradation system, with a treatment capacity of up to 100,000 cubic yards, that has been used to treat petroleum and hydrocarbon sludges.

Groundwater Technology, Inc. reportedly has a full-scale slurry biodegradation system, which employs flotation, reactor, and clarifier/sedimentation tanks in series, that has been used to treat soils contaminated with heavy oils, PAHs, and light organics.

ReTeC's full-scale slurry biodegradation system was used in two major projects: Valdosta, Georgia, and Sweetwater, Tennessee. Both projects involved closure of RCRA-regulated surface impoundments containing soils and sludges contaminated with creosote constituents and PCP. Each project used in-ground, lined slurry-phase bioreactor cells operating at 100 cubic yards per week. Residues were chemically stabilized and further treated by tillage. For final closure, the impoundment areas and slurry-phase cells were capped with clay and a heavy-duty asphalt paving [5]. ReTeC has also performed several pilot-scale field demonstrations with their system on oil refinery sludges (RCRA K048-51).

One vendor estimates the cost of full-scale operation to be $80 to $150 per cubic yard of soil or sludge, depending on the initial concentration and treatment volume. The cost to use slurry biodegradation will vary depending upon the need for additional pre- and post-treatment and the addition of air emission control equipment.

EPA Contact

Technology-specific questions regarding slurry biodegradation may be directed to:

Dr. Ronald Lewis
U.S. EPA Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, Ohio 45268
Telephone: FTS 684-7856 or (513) 569-7856.

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7.15 EXHIBIT 9 - GLOSSARY OF BIOREMEDIATION TERMINOLOGY

Aerobic Respiration
Energy-yielding metabolism in which the terminal electron acceptor for substrate oxidation is molecular oxygen.

Adaptation/Acclimation
An increase in the biodegradation rate of a chemical after exposure of the microbial community to the chemical for some period of time.

Anaerobic Respiration
Energy-yielding metabolism in which the terminal electron acceptor form substrate oxidation is an inorganic compound other than molecular oxygen, such as sulfate or nitrate.

Biodegradation
The biological transformation of an organic chemical to another without regard to extent. Biologists, however, usually use biodegradation as a synonym for mineralization.

Biogenic Compounds
Naturally occurring compounds that have been present for millions of years. Thus, there are organisms somewhere in the biosphere that can initiate their biodegradation.

Bioremediation
The manipulation of living systems to bring about desired chemical and physical changes in a confined and regulated environment.

Cometabolism/Cooxidation
The transformation of a non-growth substrate that could not occur without the presence of a growth substrate or another transformable compound.

Constitutive Enzymes
Enzyme(s) always produced by a cell regardless of the nature of the medium. An inducer compound is not required for the enzyme(s) formation.

Fermentation
Energy-yielding metabolism that involves a sequence of oxidation-reduction reactions in which both the substrate (primary electron donor) and the terminal electron acceptor are organic compounds.

Gratuitous Metabolism
Reaction involving enzymes having high substrate specificity with respect to catalytic function but low specificity with respect to substrate binding.

Inducible Enzymes
Enzymes produced by a cell in response to a specific compound that is referred to as the inducer.

Mineralization
The conversion of organic chemicals to carbon dioxide and/or methane, water, and various inorganic forms.

Non-Growth Substrate
A substrate that will not support cell division. There must be a growth substrate present in order for the transformation to occur.

7.15 EXHIBIT 9 - GLOSSARY OF BIOREMEDIATION TERMINOLOGY (continued)

Persistent Compound
A chemical that fails to undergo biodegradation under a specified set of conditions. A chemical may be inherently biodegradable yet persistent in the environment.

Recalcitrant/Refractory Compound
A compound that has an inherent resistance to any degree of biodegradation.

Substrate
The material or substance on which an enzyme reacts.

Xenobiotic Compounds
Compounds that are "foreign" to the biosphere, having been present for only an instant on the evolutionary timescale. May or may not be biodegradable.

Source: Bioremediation of Hazardous Waste Sites Workshop - Speaker Slide Copies and Supporting Information, CERI-89-11

INTERNATIONAL ENVIRONMENTAL TECHNOLOGY/ YWC MIDWEST (Geolock/Bio-Drain Treatment Platform)

TECHNOLOGY DESCRIPTION:

The Geolock/Bio-drain treatment platform is a bioremediation system that is installed in the soil or waste matrix. The technology can be adapted to the soil characteristics of the area, the concentration of contaminants, and geologic formations. The system is composed of an in-situ tank, an application system, and a bottom water recovery system.

The tank, an in-situ structure, is composed of high density polyethylene (HDPE), sometimes in conjunction with a slurry wall. An underlying permeable waterbearing zone facilitates the creation of ingradient water flow conditions. The tank defines the treatment area, minimizes intrusion of off-site clean water, minimizes the potential for release of bacterial cultures to the aquifer, and keeps contaminant concentration levels that facilitate treatment. The ingradient conditions also facilitate reverse leaching or soil washing.

The application system, called Bio-drain, is installed within the treatment area. Bio-drain delivers bacterial cultures, nutrients, and oxygen or any other proprietary chemical to the soil profile. Bio-drain acts to aerate the soil column and any standing water. This creates an aerobic environment in the air pore spaces of the soil. The cost of installation is low, and Bio-drains can be placed in very dense configurations.

Existing wells or new wells are used to create the water recovery system for removal of contaminated soil washing water. By controlling the water levels within the tank, reverse leaching or soil washing and the volume of off-site clean water entering the system can be controlled and minimized. This minimizes the potential for off-migration. It also creates a condition such that the direction of existing contaminants and bacterial degradation products is toward the surface.

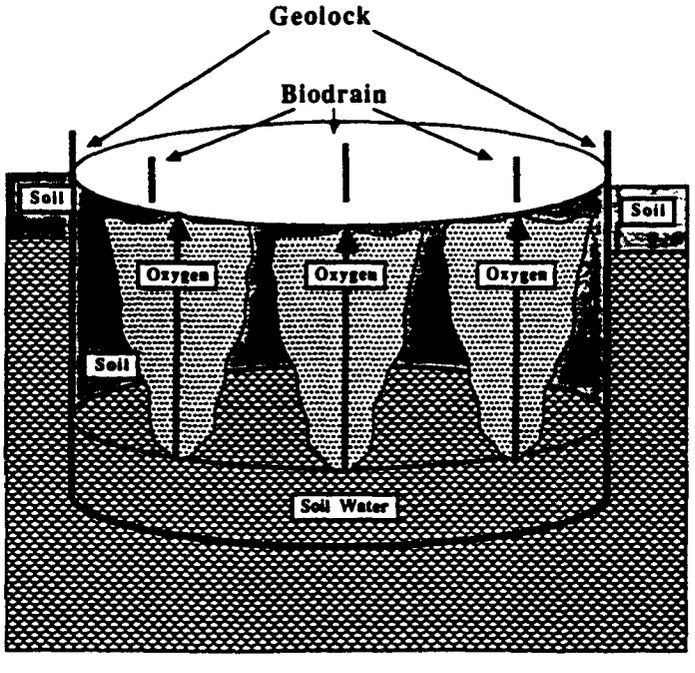

Figure 1. Geolock / Biodrain

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

Conventional biological treatment is limited by the depth of soil aeration, the need for physical stripping, or the need to relocate the contaminated media to an aboveground treatment system. The Geolock/Bio-drain treatment platform surpasses these limitations as well as reduces or eliminates the health risks associated with excavation and air releases from other treatment technologies.

WASTE APPLICABILITY:

All types and concentrations of biodegradable contaminants can be treated by this system. Through direct degradation or cometabolism, microorganisms can degrade most organic substances. Only a limited number of compounds, such as Arochlor 1254 and 1260 (PCBs) are resistant to biodegradation. Also, this technology may not be applicable to constituents resistent to degradation, including 1,4 dioxane and high concentrations of heavy metals.

Extremely dense clays may be difficult to treat with this technology. Rock shelves or boulders may render installation impossible.

STATUS:

The technology was accepted into the SITE Demonstration Program in August 1990. Preparation of the Quality Assurance Project Plan and site selection have begun.

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SITE Technology Profile

DEMONSTRATION PROGRAM

ECOVA CORPORATION
(In-Situ Biological Treatment)

TECHNOLOGY DESCRIPTION:

Ecova Corporation's bioremediation technology is designed to biodegrade chlorinated and non-chlorinated organic contaminants by employing aerobic bacteria that use the contaminants as their carbon source. This proposed technology has two configurations: in-situ biotreatment of soil and water; and on-site bioreactor treatment of contaminated ground water.

A primary advantage of in-situ bioremediation is that contaminants in subsurface soils and ground water can be treated without excavating overlying soil. The technology uses special strains of cultured bacteria and naturally occurring microorganisms in on-site soils and ground water. Since the treatment process is aerobic, oxygen and soluble forms of mineral nutrients must be introduced throughout the saturated zone. The end products of the aerobic biodegradation are carbon dioxide, water, and bacterial biomass.

Contaminated ground water can also be recovered and treated in an aboveground bioreactor. Nutrients and oxygen can then be added to some or all of the treated water, and the water can be recycled through the soils as part of the in-situ soil treatment.

Because site-specific environments influence biological treatment, all chemical, physical, and microbiological factors are designed into the treatment system. Subsurface soil and groundwater samples collected from a site are analyzed for baseline parameters, such as volatile organics, metals, pH, total organic carbon, types and quantities of microorganisms, and nutrients. A treatability study, which includes flask and column studies, determines the effects of process parameters on system performance. The flask studies test biodegradation under optimum conditions, and the column studies test the three field applications: (1) soil flushing; (2) in-situ biotreatment, and (3) in-situ biotreatment using ground water treated in a bioreactor.

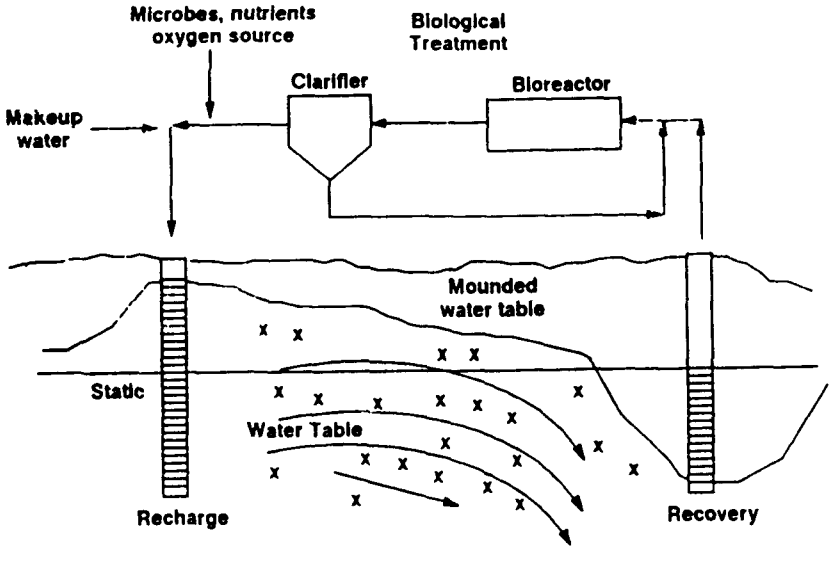

Figure 1. In situ bioreclamation processes.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

Biological processes can be applied to water, soil, sludge, sediment, and other types of materials contaminated with organic constituents. The system must be engineered to maintain parameters such as pH, temperature, and dissolved oxygen (if the process is aerobic), within ranges conducive to the desired microbial activity. The technology is applicable to chlorinated solvents and non-chlorinated organic compounds.

STATUS:

Ecova's planned demonstration of this technology on a wide range of toxic organic compounds at the Goose Farm Superfund Site in Plumstead Township, NJ was cancelled after the completion of treatability studies in April 1990. The treatability study report will be published by January 1991.

Although the demonstration was cancelled at the Goose Farm site, the technology may be demonstrated at another hazardous waste site in the future.

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206-883-1900

SITE Technology Profile

DEMONSTRATION PROGRAM

IN-SITU FIXATION COMPANY
(In-Situ Bioremediation Process)

TECHNOLOGY DESCRIPTION:

This process increases the quality and acceleration of biodegradation in contaminated soils. The specialized equipment system injects site-specific microorganism mixtures, along with the required nutrients, and homogeneously mixes them into the contami-nated soils. The injection and mixing process effectively breaks down fluid and soil strata barriers and eliminates pockets of contaminated soil that would otherwise remain untreated.

The process uses a twin, 5-foot diameter auger system powered and moved by a standard backhoe. The auger drills into contaminated soil with hollow shafts, allowing the microorganism and nutrient mixture to pass.

The allocation of the microorganisms and nutrients occurs during the initial auger action. The auger flights break the soil loose, allowing mixing blades to thoroughly blend the microorganism and nutrient mixture with the soil. This occurs in an overlapping manner, to ensure the complete treatment of all contaminated soil. The mixing action is continued as the augers are withdrawn. Treatment depth can exceed 100 feet.

Water, nutrients, and bacteria are added to the contaminant area as needed.

WASTE APPLICABILITY:

The process is applicable to contaminated soils. Different contaminants may have different degrees of success. High concentrations of heavy metals, non-biodegradable toxic organics, alkaline conditions, or acid conditions could interfere with the degradation process. Although volatiles may volatilize during remediation, it has been minimized by adding a hood around the auger assembly and treating the captured gases.

The Dual Auger System was also developed for the treatment of inorganic contaminated soils, by injecting reagent slurry into the soil to solidify/stabilize contaminated waste.

STATUS:

This technology was accepted into the SITE Program in June 1990. EPA is currently locating a site to demonstrate this project.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

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SITE Technology Profile

DEMONSTRATION PROGRAM

REMEDIATION TECHNOLOGIES, INC.
[formerly Motec, Inc.]
(Liquid/Solid Contact Digestion)

TECHNOLOGY DESCRIPTION:

This process uses liquid-solid contact digestion (LSCD) to biodegrade organic wastes. Organic materials and water are placed in a high energy environment, in which the organic constituents are then biodegraded by acclimated microorganisms.

The system consists of two or three portable tank digesters or lagoons (Figure 1): (1) a primary contact or mixing tank; (2) a primary digestion tank; and (3) a polishing tank. Treatment time may be ten days or more, depending on the type and concentration of the contaminants and the temperature in the tanks.

In the primary contact tank, water is mixed with influent sludge or soil. The mixing process is designed to achieve a 20 to 25 percent solids concentration. Water is obtained either from the contaminated source or a fresh water source. Emulsifying chemicals may be added, and pH is adjusted to increase the solubility of the organic phase. After water is added, the batch mixture is transferred to the primary digestion tank, where acclimated seed bacteria are added, and aerobic biological oxidation is initiated. Most of the biological oxidation occurs during this phase.

When the biodegradation reactions decrease significantly, the batch mixture is transferred

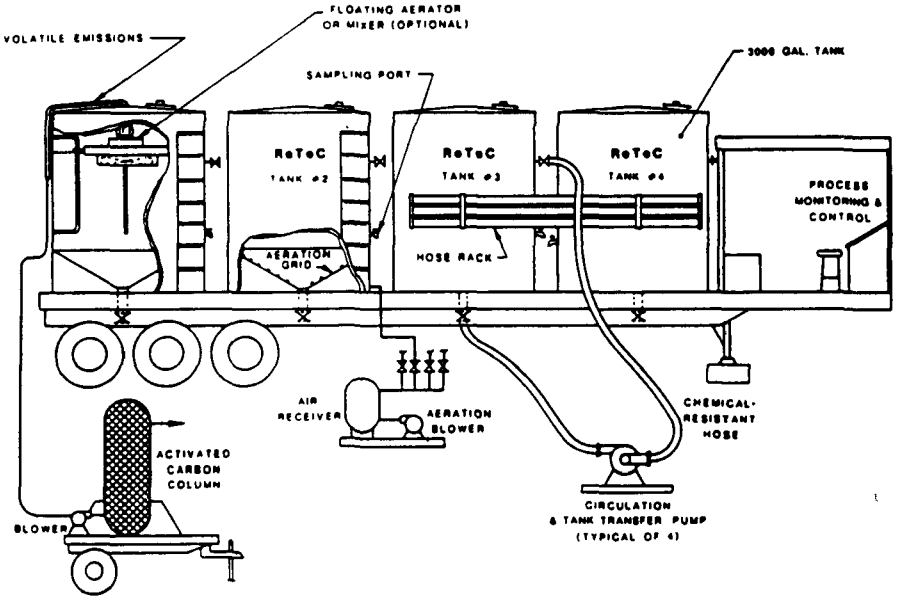

Figure 1. Mobile pilot-scale liquid solids contact treatment system.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

to the polishing tank for final treatment. Once the pH has been readjusted in the polishing cell, co-metabolites and nutrients are added to maintain and enhance the biomass. In this phase, organic constituents are degraded to target concentration levels. Because the system runs on a negative water balance, water is added throughout the process. Once target levels are reached, the supernatant from the polishing tank is recycled to the primary contact tank, and biological sludge is treated in prepared bed solid phase bioreactors.

WASTE APPLICABILITY:

The technology is suitable for treating halogenated and nonhalogenated organic compounds, including some pesticides and herbicides. LSCD has been demonstrated on liquids, sludges, and soils with high organic concentrations.

STATUS:

The developer is seeking private party co-funding for a 3 to 4 month demonstration on petroleum or coal tar derived wastes.

FOR FURTHER INFORMATION:

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SITE Technology Profile

DEMONSTRATION PROGRAM

ZIMPRO/PASSAVANT INC. (PACT®/Wet Air Oxidation)

TECHNOLOGY DESCRIPTION:

Zimpro/Passavant Inc. has developed a treatment system that combines two technologies: the PACT® treatment system and wet air oxidation (WAO). The PACT® system uses powdered activated carbon (PAC) combined with conventional biological treatment (e.g., an activated sludge system) to treat liquid waste containing toxic organic contaminants. The WAO technology can regenerate the PAC for reuse in the PACT® system. The system is mobile and can treat from 2,500 to 10,000 gallons of wastewater per day. Larger stationary systems, treating up to 53 million gallons per day, are already in operation.

In the PACT® system, organic contaminants are removed through biodegradation and adsorption. Living microorganisms (biomass) in the activated sludge system are contained in liquid suspension in an aerated basin. This biomass removes biodegradable toxic organic compounds from the liquid waste. PAC is added to enhance this biological treatment by adsorbing toxic organic compounds.

The degree of treatment achieved by the PACT® system depends on the influent waste characteristics and the system's operating parameters. Important waste characteristics include biodegradability, adsorbability, and concentrations of toxic organic compounds and inorganic compounds, such as heavy metals.

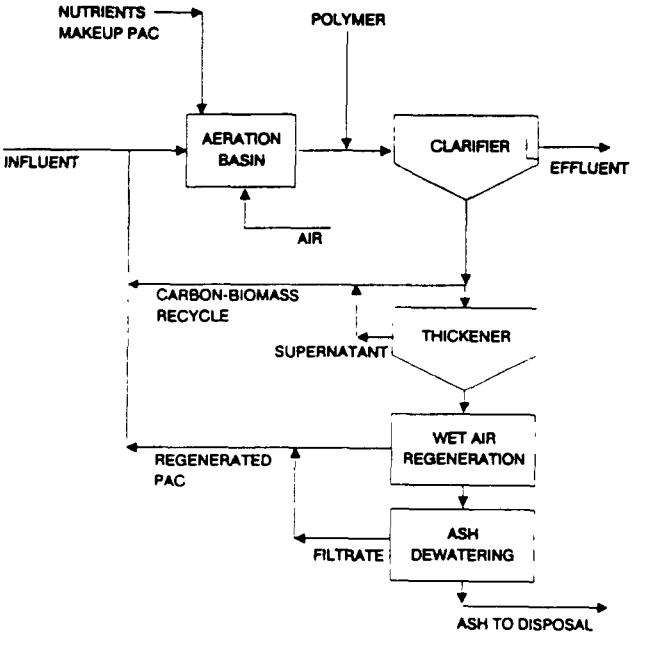

Figure 1 PACT® system with WAO.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

Major operating parameters include carbon dose, hydraulic retention time of the aeration basin, solids retention time of the biomass-carbon mixture, and biomass concentration in the system. Liquid wastes fed into the PACT® system should have sufficient nutrients (nitrogen and phosphorous) and biodegradable compounds to support the growth of active biomass in the aeration basin. The temperature of the waste should be in the range of 40° F to 100° F, and the influent pH in the range of 6 to 9. Solids retention times affect both the concentration and type of biomass in the system; these vary from 2 days to 50 days. Hydraulic retention times affect the degree of biodegradation achieved and typically range from 2 hours to 24 hours for relatively dilute wastes, such as contaminated groundwater, up to several days for concentrated wastes and leachate. Carbon doses vary widely, depending on the biodegradability and adsorptive characteristics of the contaminants in the waste. Higher PAC concentrations improve the settleability of the PAC-biomass mixture and reduce air stripping of volatile organic contaminants.

Excess solids (PAC with adsorbed organics, biomass, and inert solids) are removed periodically from the system through the system's clarifier (settling tank) or thickener (see Figure 1). These excess solids are routed to the WAO system reactor to regenerate the spent PAC and destroy organics remaining in the biomass. Temperatures and pressures in the WAO system will be about 480° F and 800 to 850 pounds per square inch, respectively. After treatment in the WAO system, the regenerated PAC may be separated from the ash formed from destruction of the biomass and returned to the aeration basin for reuse.

WASTE APPLICABILITY:

This technology is applicable to municipal and industrial wastewaters, as well as ground water and leachates containing hazardous organic pollutants. According to the developer, the PACT® system has successfully treated a variety of industrial wastewaters, including chemical plant wastewaters, dye production wastewaters, pharmaceutical wastewaters, refinery wastewaters, and synthetic fuels wastewaters, in addition to contaminated groundwater and mixed industrial/municipal wastewater.

In general, PACT® system can treat liquid wastes containing wide ranges of biochemical oxygen demand (BOD) -- 10 to 30,000 parts per million (ppm) -- and chemical oxygen demand (COD) -- 20 to 60,000 ppm. Toxic volatile organic compounds can be treated up to the level where they interfere with biomass growth, about 1,000 ppm. The developer's treatability studies have shown that the PACT system can reduce the organics in contaminated groundwater from several hundred ppm to below detection limits (parts per billion range).

STATUS:

Plans are underway to secure wastewater for the system to treat. Several sites have been studied for suitability.

FOR FURTHER INFORMATION:

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SITE Technology Profile

DEMONSTRATION PROGRAM

BIOVERSAL USA, INC.
(Biogenesis Soil Cleaning Process)

TECHNOLOGY DESCRIPTION:

The BioGenesis™ process uses a specialized truck, gravity and cyclone separators, and a bioreactor to wash contaminated soil. The wash rate for hydrocarbon contamination up to 5,000 ppm is 25 tons per hour; higher contamination levels require slower wash rates. After the first wash, 100 to 200 ppm of the residuals remain. A second wash reduces residuals even further. A single wash removes 95% to 99% of hydrocarbon concentrations up to 16,000 ppm. One or two additional washes are used for concentrations up to 45,000 ppm.

The residuals biodegrade at an accelerated rate due to contact with BioVersal™, a light, alkaline, organic formula used to reduce oil contamination. Figure 1 shows the soil-cleaning procedure. Twenty-five tons of contaminated soil are dumped into a mixture of water and BioVersal™. For 15 to 30 minutes, aeration equipment agitates the mixture, washing the soil and encapsulating oil molecules with BioVersal™.

After washing, the liquid products are recycled or treated, and the soil is dumped out of the soil washer. The bioreactor processes the minimal amount of wastewater produced by the soil washer. Recovered oils are recycled.

PCBs, metals, and other hazardous materials are extracted in the same manner, then processed using specific treatment methods. All equipment is mobile, and treatment is normally on-site.

WASTE APPLICABILITY:

This technology is applicable to soil contaminated with volatile and nonvolatile hydrocarbons. These include asphaltenes, PCBs, polycylic hydrocarbons, and epichlorhydrin.

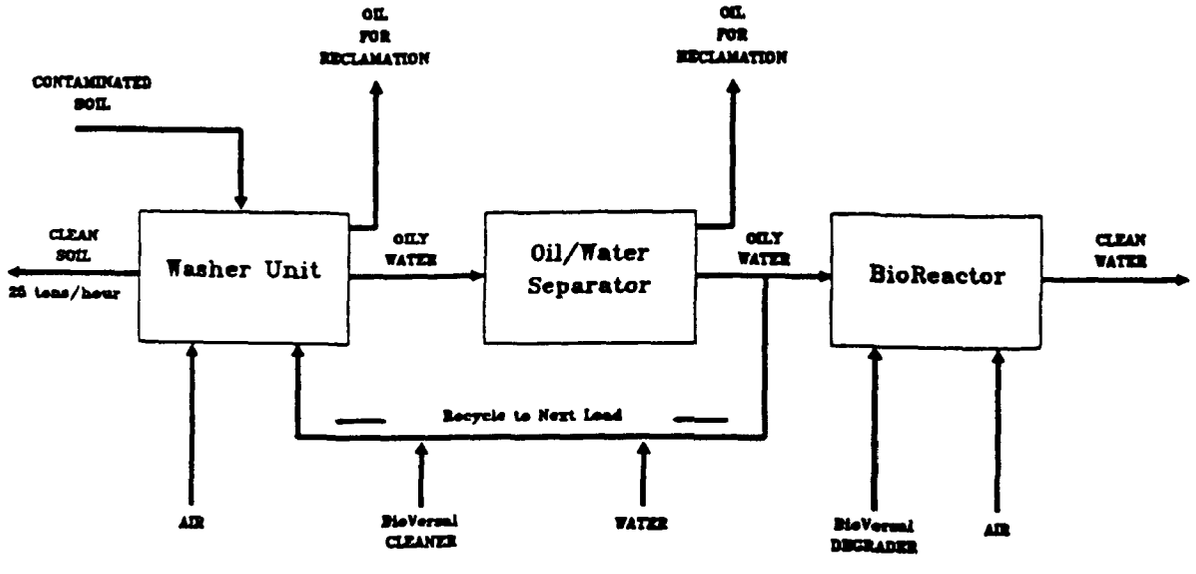

Figure 1. Biogenesis Soil Cleaning Process

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

STATUS:

This technology is used commercially in Europe. The technology was accepted into the SITE Demonstration Program in July 1990.

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(703) 250-3442

SITE Technology Profile

DEMONSTRATION PROGRAM

BIOTROL, INC.
(Biological Aqueous Treatment System)

TECHNOLOGY DESCRIPTION:

The Biotrol Aqueous Treatment System (BATS) is a patented biological treatment system that is effective for treating contaminated ground water and process water. The system uses an amended microbial mixture; that is, a microbial population indigenous to the wastewater to which a specific microorganism has been added. This system removes the target contaminants as well as the naturally occurring background organics.

Figure 1 is a schematic of the BATS. Contaminated water enters a mix tank, where the pH is adjusted and inorganic nutrients are added. If necessary, the water is heated to an optimum temperature, using a heat exchanger to minimize energy costs. The water then flows to the reactor, where the contaminants are biodegraded.

The microorganisms, which perform the degradation, are immobilized in a three-cell, submerged, fixed-film bioreactor. Each cell is filled with a highly porous packing material

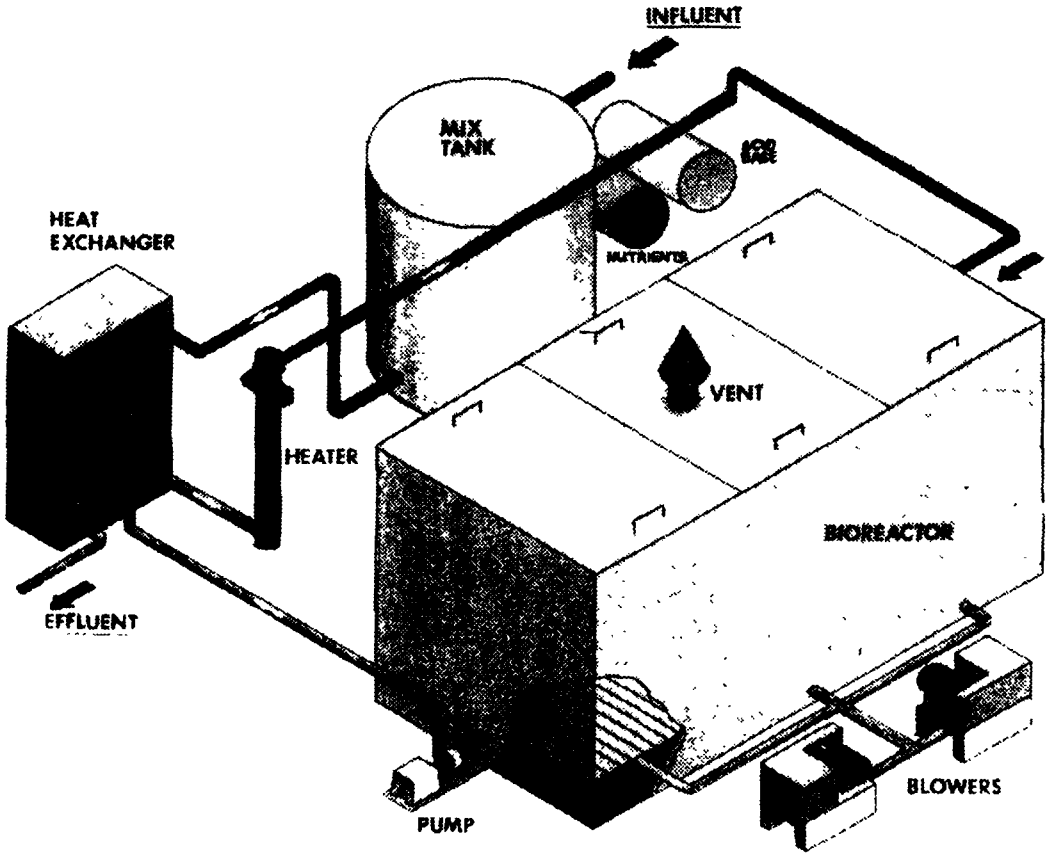

Figure 1. Bioreactor Processing System.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles EPA/540/5-90/006 (1990).

to which the microbes adhere. For aerobic conditions, air is supplied by fine bubble membrane diffusers mounted at the bottom of each cell. The system may also run under anaerobic conditions.

As the water flows through the bioreactor, the contaminants are degraded to carbon dioxide, water, and chloride ion. The resulting effluent may be discharged to a Publicly Owned Treatment Works (POTW) or may be reused on-site. In some cases, discharge with a NPDES permit may be possible.

WASTE APPLICABILITY:

This technology is applicable to a wide variety of wastewaters, including ground water, lagoons, and process water. Contaminants amenable to treatment include pentachlorophenol, creosote components, gasoline and fuel oil components, chlorinated hydrocarbons, phenolics, and solvents. Other potential target waste streams include coal tar residues and organic pesticides. The technology may also be effective for treating certain inorganic compounds such as nitrates; however, this application has not yet been demonstrated. The system does not treat metals.

STATUS:

In 1986-87, Biotrol performed a successful 9-month pilot field test of BATS at a wood preserving facility. Since that time, several other demonstrations and commercial installations have been completed. The SITE demonstration of the BATS technology took place from July 24 to September 1, 1989 at the MacGillis and Gibbs Superfund site in New Brighton, Minnesota. The system was operated continuously for six weeks at three different flow rates.

DEMONSTRATION RESULTS:

Results from the demonstration showed that PCP was reduced to less than 1 ppm at all flow rates. Removal percentage was as high as 97% at the lowest flow rate. The Technology Evaluation Report will be available in December 1990.

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612-448-2515

EPA/540/2-91/007 No.2 March 1991

EPA
U.S. Environmental Protection Agency

Office of Solid Waste and Emergency Response

Office of Research and Development

BIOREMEDIATION IN THE FIELD

An information update on applying bioremediation to site clean-up.

UPDATE ON THE BIOREMEDIATION FIELD INITIATIVE

The Bioremediation Field Initiative was established to provide EPA and State Project Managers, consulting engineers and industry with timely information regarding new developments in the application of bioremediation at hazardous waste sites. In addition, the initiative will fully evaluate the performance of selected full-scale field applications, provide technical assistance to RPMs and OSCs, and develop a treatability database to be available through the Alternative Treatment Technologies Information Center (ATTIC.)

The initiative is currently moving ahead with it's field evaluations of bioremediation. The Allied Signal site in St. Joseph, Michigan is on board for an evaluation of methylotropic technology on a TCE and vinyl chloride plume. Dr. John Wilson, developer of the methylotropic method, is the EPA project officer for the evaluation. In this issue he provides an update on technology being developed for the site. To date, a tentative work plan has been established and treatability studies are being carried out. The pilot scale demonstration is expected to be run this summer.

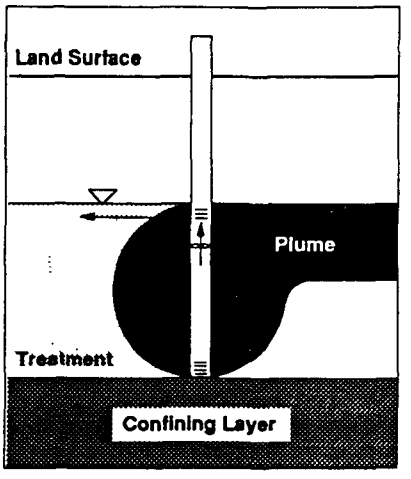
A second site, located in Libby, MT has been identified as a good candidate for an evaluation of land treatment, which is currently being implemented on creosote and PCP contaminated soils, and of an in situ bioremediation system with an above ground fixed film bioreactor for contaminated ground water, which is now in design. Dr. Huling, the project officer at EPA's Ada laboratory, provides an update on the Libby site and the proposed evaluation on page 2. Both of these sites are being remediated by the responsible parties who cooperated with EPA to initiate the evaluations.

One other site that was under consideration for the field evaluation is being screened further prior to inclusion. Technical issues with the operating system at the site may not allow an evaluation this summer. Therefore, other sites are now being looked at as potential alternates. The UST site under consideration for the field evaluation is currently seeking funding for the project.

Another ongoing activity being promoted under the Field Initiative is providing technical assistance on bioremediation projects to EPA Regions through the EPA laboratories. See the article on page 16 for more news on the Superfund Technical Support Program. For further information on the Field Initiative, write to the contact listed on page 15.

RSKERL Proposes New Injection Well Design for In situ Biotreatment of a TCE Plume, St. Joseph, Michigan

The Western Region Hazardous Substance Research Center (WRHSRC) at Stanford University recently conducted a treatability study utilizing in situ bioremediation to remediate vinyl chloride and trichloroethylene contamination in ground water at the Allied Signal/Bendix site, St. Joe, Michigan. Researchers had previously discovered that by mixing ground water and a solution of oxygen and methane, the vinyl chloride and trichloroethylene contamination could be biodegraded in soil cores. However, in the field, simply injecting solutions of oxygen and methane into an aquifer does not adequately mix them with the contaminated ground water. To remedy this problem, the WRHSRC has developed an in situ treatment unit that enhances this mixing. The unit consists of a well with two screens, a pump, and mixing apparatus. One well screen is located at the bottom of the aquifer and the other is at the water table. Contaminated ground water is drawn into the well through the lower screen, where it is amended with oxygen and methane, then pumped back into the aquifer through the water table screen. The pumping rate in the treatment unit can be adjusted to recirculate the plume through the treatment unit as many times as is necessary to meet cleanup standards. The WRHSRC is currently writing a computer code to describe the three dimensional flow through the zone of influence of the treatment unit. This new computer code will be used to design these treatment systems and identify optimum well placements and pumping rates. For further information, contact John Wilson at FTS: 743-2259 or 405-332-8800.



New Injection Well Design for In situ Bioremediation

Printed on Recycled Paper

Field Evaluation of Bioremediation Techniques Proposed at the Libby, Montana Superfund Site

EPA's Robert S. Kerr Environmental Research Laboratory is currently negotiating with the potentially responsible party at the Libby, Montana Superfund Site to implement a bioremediation performance evaluation for the field initiative. The site is contaminated with creosote, pentachlorophenol and a fuel carrier as a result of previous wood preserving operations.

Bioremediation activities consist of land treatment of the contaminated soil, in-situ treatment of both the ground water and aquifer material, and above-ground bioremediation of the ground water. The proposed performance evaluation will address each of these bioremediation activities.

The objectives of the performance evaluation will be to identify both the merits and limitations of bioremediation from a qualitative and a quantitative perspective. The project will involve the compilation, assimilation, and interpretation of monitoring data from the various biological processes. In addition, the monitoring of laboratory and field activites will further develop our understanding of the processes and strategies that contribute to successful site remediation using biological techniques. For further information contact Scott Huling at FTS: 743-2313 or 405-332-2313.

Kerr Laboratory Announces Field Validation of Three Bioremediation Techniques for Fuel Spills

During field evaluations of hazardous waste remediation technologies, several removal processes often operate on the contaminants of interest at the same time. This makes it difficult to determine which aspect of the treatment actually produced the observed remediation. It also makes it difficult to extrapolate remediation results to other sites and scenarios.

A contaminated site in Park City, Kansas will provide staff at EPA's Robert S. Kerr Environmental Laboratory with an opportunity to divide an area affected by a homogeneous fuel spill into discrete blocks, and apply different experimental bioremediation treatments to each block. The objective of this study will be to evaluate the relative efficacy of (1) BTEX fermentation alone, (2) BTEX denitrification alone, and (3) BTEX denitrification supplemented with oxygen, for remediation of subsurface contamination with refined petroleum hydrocarbons.

The study site is in the flood plain of the Arkansas River, where there is 15 to 20 feet of clay overlying a sand aquifer. The water table is near the contact between the sand and the clay. Bedrock is at 45 to 50 feet.

Sometime in the 1970s, a buried pipe line at an oil refinery in Park City, Kansas, started leaking a variety of refined petroleum products and petroleum feedstocks below the clay into the water table aquifer. The spill contaminated ground water near Park City's municipal well #6 in February 1980. To intercept the flow of hydrocarbons from the pipeline to the well, two trenches were excavated to the water table for free product recovery. As a means of disposal, the petroleum in the trenches was occasionally set afire. The west trench was backfilled in August of 1982, the east trench was filled in August of 1984. In 1990, the PRP installed approximately 500 shallow injection wells that are screened just above the water table. These wells were constructed on a 20-foot grid spacing and covered the entire area affected by the spill.

The spill area will be subdivided into three plots of about an acre each. Water from the municipal supply well will be pumped and recirculated to the aquifer through the injection wells at the rate of 400 gpm. Each of the three experimental plots will receive approximately 130 gpm. At a pumping rate of 400 gpm, it is estimated that the water will require an average of 6.4 days to recirculate. To maintain the demonstration in a cone of depression, water will also be pumped from a second nearby well. To act as a tracer, and to enable estimation of the volume of water in the recirculation loop, the recirculated water will be amended with sodium bromide at 50 mg/l of bromide.

The recirculated water will also be amended with ammonium nitrate at 5 mg/l as nitrogen. The water distributed to two of the plots will be amended with potassium nitrate at 10 mg/l as nitrogen. The water distributed to one of the plots will be amended with 5 mg/l oxygen.

Microcosm studies will be conducted on two on-going remediations. Cores will be acquired before and after application of nitrate and analyzed by GC/MSto determine the extent of remediation. The field evaluation will be conducted this year and is being performed under a Cooperative Research Demonstration Agreement with Coastal Remediation Company. For further information contact John Wilson at FTS: 743-2259 or 405-332-8800.

Biodegradation of Trichloroethylene by a Genetically Modified Bacterium

One of the most prevalent environmental pollutants is the industrial degreaser, trichloroethylene (TCE). Its persistence is largely due to two fundamental properties: 1) It has a relatively high water solubility, and therefore fails to adhere to soil and aquifer materials, allowing rapid vertical movement into aquifer systems; and 2) Despite breaking down quickly in sunlight, it is very persistent below the ground because it is not subject to chemical or biological transformations of any significant extent.

Once TCE is released to the environment, naturally occurring bacteria do not readily degrade it unless it is present with

other, more easily degraded organics such as toluene or phenol. This problem has been the subject of research at the EPA research laboratory in Gulf Breeze, Florida for the last several years. Researchers there now report the development of a strain of Pseudomonas cepacia called G4 5223 Phel, that produces a TCE degrading enzyme without the need for the presence of other organics. All evidence indicates that the new strain is very stable and capable of functioning under a wide variety of environmental conditions. Unlike cloned bacterial genes currently available for TCE degradation, G4 5223 Phel is not a product of recombinant genetics and therefore is not subject to regulations imposed on such constructed bacteria.

Gulf Breeze researchers envision this bacteria being used during in situ aquifer restoration, in bioreactors for contaminated materials and in biofilters for atmospheric treatment of chloroethylenes. In addition to TCE, G4 5223 Phel can also degrade a wide spectrum of other pollutants including vinyl chloride, DCE, benzene, phenol, toluene, xylenes, and cresols. Research is already underway at Gulf Breeze to extend this list of "edible pollutants." For further information, contact Malcolm Shields at FTS: 228-9333 or 904-934-9333.

New Biological Assay Techniques to be Tested During SITE Demonstration at American Creosote

This spring, the SITE Demonstration Program will work with Southern Bio Products, Inc. to conduct a pilot-scale technology demonstration using bioremediation to treat creosote and PCP-contaminated soil and ground water at the American Creosote Works Superfund site in Pensacola, Florida. The multi-phase biotreatment strategy under evaluation has combined physical separation technologies and microorganisms which utilize recalcitrant creosote constituents as a primary energy source for growth.

In conjunction with the normal chemical analysis used during a SITE demonstration, various biological analyses will be performed through a cooperative research and development agreement with the U.S. EPA Environmental Research Laboratory at Gulf Breeze, Florida. Embryonic inland silversides (*Menidia beryllina*) have recently been identified as sensitive and accurate indicators for PCP and creosote-related pollutants in an aqueous phase. During this demonstration, these organisms will be used to generate toxicity, teratogenicity and mutagenicity data on starting and end point samples. Other biological assays will include acute toxicity tests conducted with a saltwater invertebrate, *Mysids*. Lastly, selected samples will be tested using EPA established methods to estimate the potential for chronic effects to fish and invertebrates.

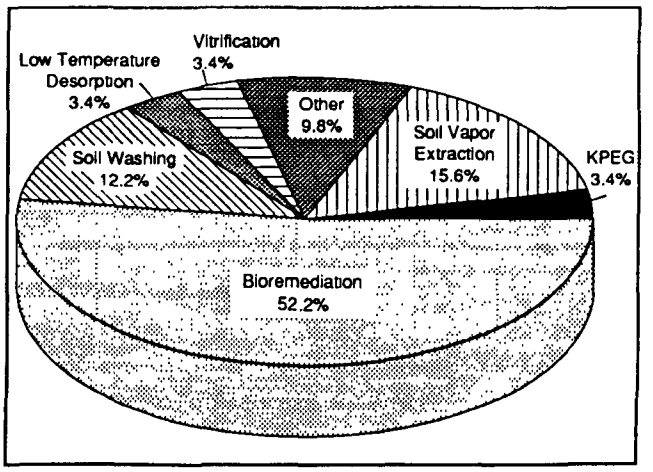
The results of this pilot scale study could facilitate the development of standard test protocols that use site-specific animals in routine testing procedures. For further information, contact James Mueller at FTS: 228-9282 or 904-934-9282.

EPA's Technical Support Project Provides Assistance to Eighteen Superfund Sites Utilizing Bioremediation in FY '90

Since the inception of EPA's Technical Support Project (TSP) in 1988, over 50% (47) of the requests for technical assistance received regarding innovative technologies have addressed bioremediation. At least 7 evaluations of bioremediation sites and 11 work plan and design reviews have been completed or are currently in progress.

The Superfund Technical Support Project (TSP) is a joint effort of OSWER's Technology Innovation Office and the Office of Research and Development (ORD). The goal of the program is to provide technical assistance to Remedial Project Managers (RPMs) and On-Scene Coordinators (OSCs). The network of technical resources established by the program has to date undertaken 750 technical assistance projects, delivered technical workshops regarding specific Superfund sites and prepared 20 issue papers regarding critical areas of remedial technology development. The program has given ORD a better understanding of Regional technical needs and enabled the Regions to more consistently evaluate treatment options. (For more detailed information regarding services provided by the TSP, see page 16.)

One example of a TSP project undertaken by one of the centers, the Ground-Water Fate and Transport Technical Support Center in Ada, Oklahoma, is oversight support of the PRP and technical assistance at the Baxter/IP/Rosenberg Superfund site in Region IX. The site involves the contamination of both soil and groundwater with PAHs, PCP, TCP, and metals. Initial site data indicated that high metal concentrations might inhibit bioremediation, so the center is assisting the Region in conducting tests to determine if the microbes can acclimate to the presence of metals.



FY'88-90 Innovative Technology Assistance Requests

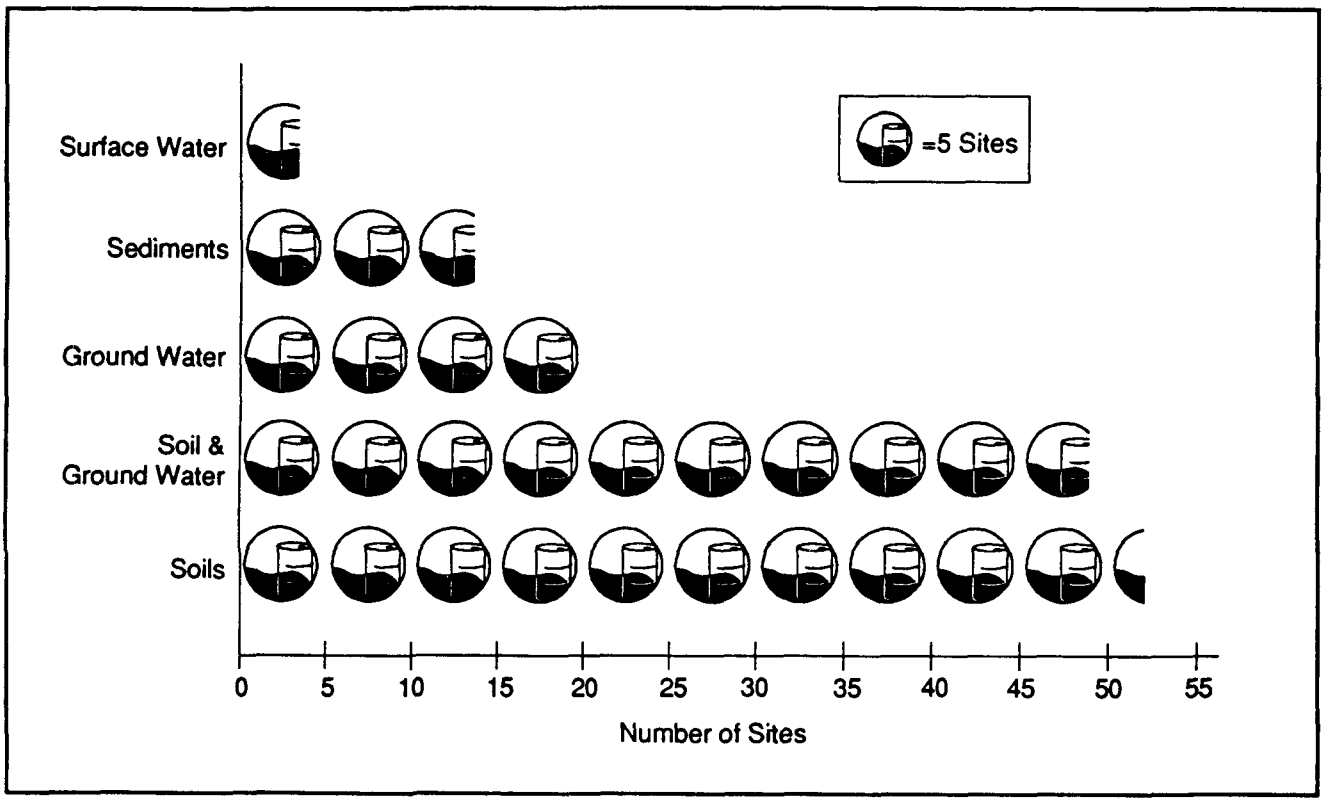
Over 140 Bioremediation Projects Identified

The Bioremediation Field Initiative has identified over 140 sites across the country where bioremediation projects are being considered, planned, or implemented. Table 1 lists these sites by EPA Region and provides some basic information concerning each of them. This table has been updated since the last issue of *Bioremediation in the Field* and more than half of the site entries contain new information. Those site entries with new information have been marked with a star. As part of this update, six sites have been dropped from the original table published in November 1990 because bioremediation is no longer being considered as a remedial alternative. About a dozen new sites have been added to the table; these are noted by the symbol, ▲ after the site name.

Analysis of the data reported by the site managers indicates that soil alone, and soil and ground water together, are the media most often treated with bioremediation. Ground water only, sediments, and surface water are also treated using bioremediation, but much less often.

The data also indicate that in-situ treatment is the most commonly employed bioremediation technique, followed by land treatment and treatment in a bioreactor. Many sites are or will employ more than one technique. Over 80 sites employing in-situ treatment have been identified, whereas over 60 sites each have chosen land treatment or treatment in a bioreactor. Managers at another 40 sites listed on Table 1 have yet to decide which, if any, biotreatment technology to employ.

In the coming months, TIO will conduct more detailed analyses of the types of contamination identified and the clean-up goals being set for all identified bioremediation sites. To accomplish this task, in-depth contaminant information is needed. TIO will be sending an easy-to-complete matrix to all participating project managers that will ask for specific detailed information. Your cooperation in this project will be appreciated.



Types of Media Treated by Bioremediation

The Bioremediation Field Initiative is a cooperative effort among the Technology Innovation Office (TIO), Office of Solid Waste and Emergency Response (OSWER), and the Office of Technology Transfer and Regulatory Support (OTTRS), the Office of Environmental Engineering and Technology Demonstration (OEETD), Office Research and Development (ORD). Major contributors to the initiative include the waste programs in the EPA Regional Offices and the following laboratories in ORD: Ada, OK; Athens, GA; Cincinnati, OH; Gulf Breeze, FL; and Research Triangle Park, NC.

TABLE 1

CERCLA/RCRA/UST SITES CONSIDERING, PLANNING, OR OPERATING FULL-SCALE BIOREMEDIATION SYSTEMS

Rgn	Site/Location/Lead	Contact/Phone Number	Contaminants/Media	Status	Clean-up Levels	Treatment
I	Baird & McGuire Holbrook, MA Fund lead	Paula Fitzsimmons 617-573-5738 FTS 833-1738	Pesticides (chlordane), dioxin, arsenic/groundwater	Under construction; ROD signed 9/30/86	State of MA drinking water standards	Bioreactor
I	Charles George Landfill* Tinsboro, MA Fund lead	Dave Dickerson 617-573-5735 FTS 833-1735	Arsenic, benzene, toluene, ethyl benzene, xylene, tetrahydrofurans/groundwater, leachate, landfill gas	ROD signed 9/88; initial treatability studies completed 6/90	MCLs and risk-based levels for groundwater and leachate	Bioreactor (activated sludge) for groundwater and leachate treatment
I	Charlestown Navy Yard Boston NHP National Park Service Boston, MA State-lead enforcement	Stephen Carlson 617-242-5680	PAHs from creosote/sediments	Planning pilot project for FY 91	Not yet established	In situ
I	General Electric▲ Pittsfield, MA TSCA lead	Joan Blake 202-382-6236 FTS 382-6236	PCBs/river sediment, soils	Undergoing pilot treatability studies	2 ppm per peak	Ex situ
I	General Electric Pittsfield, MA TSCA lead	Joan Blake 202-382-6236 FTS 382-6236	PCBs/pond, river sediment	Undergoing pilot treatability studies	2 ppm per peak	In situ
I	Hamilton Standard* Windsor Locks, CT RCRA lead	Gina Snyder 617-573-9674 FTS 833-1874	PCBs, petroleum hydrocarbons/soil	Planning to conduct treatability studies in FY 91	Not yet established	In situ
I	Iron Horse Park Billerica, MA PRP lead	Don McElroy 617-223-5518 FTS 833-1518	Petroleum hydrocarbons/soil	Treatability studies completed 1989; ROD signed 9/15/88; currently in design stage	60-80% removal or less than 1 ppm PAH; 50-60% removal of PHCs; nC_{17}/pristane ratio < or =0.2	Excavate to treatment cell-surface treatment
I	Pine Street Canal Burlington, VT Fund lead	Ross Gilleland 617-573-5766 FTS 833-1766	Coal tar, PAHs/soils, sediments, groundwater	Conducting bench-scale tests, Fall 1990; supplemental RI/FS in progress	Not yet established	Soil: in situ Groundwater: fixed film reactor
I	Sylvester Nashua, NH State lead enforcement	Chet Janowski 617-573-9623 FTS 833-1623	Phenols, MEK, acetone/groundwater	Treatability study complete; conducting remediation since July 1986	State of NH drinking water standards	Bioreactor (activated sludge with extended air)
II	Alcoa Massena, NY	Lisa Carson 212-264-6857 FTS 264-6857	PCBs/river sediments	Currently in RI stage	Not yet established	Undetermined
II	American Linen* Stillwater, NY Enforcement lead	Frank Peduto NYSDEC 518-457-2462	BTX, PAHs, VOCs, VTX/soil	Began land treatment operations 9/90		Land treatment
II	FAA Technical Center* Atlantic County, NJ PRP lead	Carla Struble 212-264-4595 FTS 264-4595	JP-4 jet fuel/soil, groundwater, floating product	ROD signed 9/29/89; currently in RD stage	NJ soil action levels; NJ MCLs for drinking water	Free product extraction and off-site cement kiln incineration; groundwater extraction and addition of nutrients for subsequent reinjection and in situ biodegradation of VOCs; soil venting; use of off-gas treatment unit for off-gas from soil venting, consisting of either a catalytic incinerator for combustion of VOCs to carbon dioxide and water, or activated carbon adsorption of VOCs

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Shading depicts a non-CERCLA site.

CERCLA/RCRA/UST SITES CONSIDERING, PLANNING, OR OPERATING FULL-SCALE BIOREMEDIATION SYSTEMS

Rgn	Site/Location/Lead	Contact/Phone Number	Contaminants/Media	Status	Clean-up Levels	Treatment
II	GEMS Landfill* Camden County, NJ State lead	Matt Westgate 212-264-3406 FTS 264-3406	Various organic and inorganic compounds/groundwater, leachate	Phase I FS underway; Phase II construction of remedial action in the design phase	Not yet established	Phase I - cap; Phase II - groundwater pre-treatment and disposal at publicly owned treatment works
II	General Electric* State lead	Jim Harrington NYSDEC 518-457-3957	PCBs	Research/treatability studies	Not yet established	Possibly bioremediation
II	General Motors* Massena, NY Enforcement lead	Lisa Carson 212-264-6857 FTS 264-6857	PCBs, PAHs, volatiles/soil, sludge, sediment, groundwater	Conducting bench-scale studies; ROD signed 12/17/90; beginning negotiations for conducting treatability studies	Proposed 10 ppm PCBs (soil), 1 ppm PCBs (sediment)	Undetermined - possibly biological treatment
II	Knispel Construction Site Horseheads, NY State lead	Frank Peduto NYSDEC 518-457-2462	Gasoline, benzene/soil, groundwater	Remediation completed 10/89	Drinking water standards	In situ (subsurface)
II	Nascolite* Millville, NJ Federal lead	Farnaz Saghafi 212-264-4665 FTS 264-4665	Methylmethacrylate, volatiles and semi-volatiles/soil, groundwater	Soil treatability studies conducted 9/90; ROD scheduled for 1991; treatability studies for groundwater underway; ROD signed 1988	NJ interim soil action levels for methylmethacrylate: 5 ppm (surface soil); 50 ppm (subsurface soil); and 350 ppb (groundwater)	Soil: proposed plan calls for extraction/solidification or soil washing - residuals from soil washing may be treated by bioremediation; Groundwater: Undetermined, possibly bioremediation
II	Osmose* Buffalo, NY State lead	Jim Harrington NYSDEC 518-457-3957	Creosote, fuel oil/soil	Land treatment ongoing	Not yet established	Land treatment
II	Renora, Inc., NJ*	Joyce Harney 212-264-6313 FTS 264-6313	PAHs, petroleum hydrocarbons/soil	Treatability study complete; bioremediation ineffective; phase II feasibility study in progress	PAHs 10 ppm; petroleum hydrocarbons 1000 ppm	Undetermined
II	Reynolds Metals Massena, NY	Lisa Carson 212-264-6857 FTS 264-6857	PCBs/river sediments	Currently in RI stage	Not yet established	Undetermined
II	Syracuse* UST lead	Chris O'Neill NYSDEC 518-457-2462	Gasoline, fuel oil/soil, groundwater	In discussion phase	Groundwater standards; proposed draft soil standards	Undetermined
III	ARC Gainesville, VA RCRA lead	Robert Stroud 215-597-8214 FTS 597-8214	Chlorobenzene/soil	Treatability study conducted 6/90; planning pilot study	Unknown	Bioremediation unit on-line since 10/89
III	Atlantic Wood* Portsmouth, VA PRP lead	Drew Lausch 215-597-1727 FTS 597-1727	PAHs from wood preserving/soil, groundwater	RI/FS ongoing; ROD scheduled for 6/91	Not yet established	Undetermined
III	Avtex Fibers Front Royal, VA PRP lead	Bonnie Gross 215-597-9023 FTS 597-9023	Arsenic, zinc, lead, carbon disulfide, hydrosulfide, phenol, cadmium/ groundwater	Treatability study planned	.05 mg/l arsenic; 5 mg/l zinc; .05 mg/l lead; .7 mg/l carbon disulfide; .3 mg/l phenol; .01 mg/l cadmium (not yet established for hydrosulfide)	Biological waste water treatment
III	Drake Chemical Lock Haven, PA Fund lead	Roy Schrock 215-597-0913 FTS 597-0913	Pesticides, DCE/soil, groundwater	Planning treatability study	MCLs	BACT
III	L.A. Clarke & Son* VA Enforcement lead	Gene Wingert 215-597-0517 FTS 597-0517	Creosote/soil	Treatability study and RI/FS ongoing; ROD signed 1/92	10 ppm carcinogenic PAHs	In situ (surface and subsurface)
III	Leetown Pesticides Leetown, WV Federal lead	Andy Palestini 215-597-1286 FTS 597-1286	DDT, lindane/soil	Treatability study conducted Spring 1990; now re-evaluating remedial action	300 ppb DDT; not yet established for lindane	Undetermined

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CERCLA/RCRA/UST SITES CONSIDERING, PLANNING, OR OPERATING FULL-SCALE BIOREMEDIATION SYSTEMS

Rgn	Site/Location/Lead	Contact/Phone Number	Contaminants/Media	Status	Clean-up Levels	Treatment
III	Ordinance Works Disposal Areas, WV* Enforcement lead	Drew Lausch 215-597-1727 FTS 597-1727	PAHs/soil	ROD signed 9/29/89; currently conducting treatability studies; unilateral administrative order issued 6/20/90	45 ppm carcinogenic PAHs	Land treatment
III	Whitmore Labs* Myerstown, PA Fund lead	Tony Dappolone 215-597-3153 FTS 597-3153	Arsenic, aniline, still bottom wastes/soil, groundwater, sludges (only certain soils are targeted for bioremediation)	Limited treatability study completed 6/90; ROD signed	Arsenic above background levels; Saturated soils: benzene .002 mg/kg; trichloroethene .004 mg/kg; tetrochloroethene .012 mg/kg; aniline .002 mg/kg; Unsaturated soils: benzene .009 mg/kg; trichloroethene .017 mg/kg; tetrochloroethene .051 mg/kg; aniline .009 mg/kg	Biological treatment (treated soils will be disposed of offsite); clay and soil capping
IV	Alabama State Docks* Mobile, AL RCRA lead	Jason Darby 404-347-3433 FTS 257-3433	PCP, creosote/groundwater, soil	Preparing to do treatability study	Not yet established	Undetermined
IV	American Creosote Works* Jackson, TN Unit 1 Fund lead	Tony DeAngelo 404-347-7791 FTS 257-7791	Creosote/soil	Treatability study planned	100 ppm for 6-8 indicators	Land treatment
IV	American Creosote Works* Jackson, TN Unit 3 Fund lead	Tony DeAngelo 404-347-7791 FTS 257-7791	Creosote/soil	Remedial study planned	100 ppm for 6-8 indicators	Land treatment
IV	American Creosote Works* Pensacola, FL Fund lead	Natalie Ellington 404-347-2643 FTS 257-2643	Creosote, PAHs, PCP, dioxins/soil	ROD 9/89 - unit 1; bench-scale treatability study completed 9/90 by Gulf Breeze Labs; ROD 6/91 - unit 2	Surface soils: 30 ppm PCP; 50 ppm carcinogenic PAHs; 2.5 ppb dioxins	Soil washing, bioreactor
IV	Brown Wood Preserving Live Oaks, FL Enforcement lead	Martha Berry 404-347-2643 FTS 257-2643	PAHs, creosote/soil	Last load of contaminated soil in surface treatment area (about finished); will monitor 3 years; treatability study conducted	100 ppm PAHs total	Land treatment; surface treatment lined with clay berms 5-6'
IV	Cape Fear Wood Preserving* Fayetteville, NC Fund lead	Jon Bornholm 404-347-7791 FTS 257-7791	PAHs, arsenic, creosote, chromium/soil, groundwater	Treatability studies ongoing	Soil: 94 mg/kg arsenic, 2.5 mg/kg carcinogenic PAHs, 100 mg/kg total PAHs; Groundwater: 10 ug/l carcinogenic PAHs, 14,350 ug/l noncarcinogenic PAHs; Surface water: 12 ug/l arsenic Sediments: 94 mg/kg arsenic, 3 mg/kg total PAHs	Soil washing followed by treatment in bioreactor
IV	Carolawn* Carolawn, SC Enforcement lead	Al Cherry 404-347-7791 FTS 257-7791	VOCs/groundwater	Planning bench-scale studies; ongoing remedial design	Acetone 710 ug/l; cis-DCE 70 ug/l; trans-DCE 120 ug/l; TCA 200 ug/l; TCE 5 ug/l; Pb 5 ug/l	
IV	Celanese Fibers Operations* Shelby, NC PRP lead	Ken Mallary 404-347-7791 FTS 257-7791	Ethylene glycol, benzene, acetone chromium/groundwater; bis(2-ethylhexyl)phthalate/ sediments; chromium, antimony, acetone/soil	Bioreactor on-line since 8/2/89; treatability studies complete	State of North Carolina MCLs	Sequencing batch reactor
IV	City Industries* Winter Park, FL Fund (for treatability studies and RD); Enforcement lead for RA	Diane Scott 404-347-2643 FTS 257-2643	Acetone, MEK, TCE, TCA/groundwater	Treatability study to be initiated 2nd quarter FY 91	Varied, based on Reference Dose Limits and Federal and State drinking water standards: 700 ug/l acetone; 200 ug/l MEK; 3.0 ug/l TCE	Pump and treat, air stripping, carbon adsorbtion, and/or biological oxidation
IV	Coleman-Evans White House, FL Fund lead	Tony Best 404-347-2643 FTS 257-2643	PCP/soil, groundwater	Remedial design underway; pilot study planned	25 ppm sediments, soil; 1 ppm groundwater	Bioreactor

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CERCLA/RCRA/UST SITES CONSIDERING, PLANNING, OR OPERATING FULL-SCALE BIOREMEDIATION SYSTEMS

Rgn	Site/Location/Lead	Contact/Phone Number	Contaminants/Media	Status	Clean-up Levels	Treatment
IV	Dubose Oil Cantonment, FL* Enforcement lead	Martha Berry 404-347-2643 FTS 257-2643	Oil, minimal PCP/soil	Currently in technology selection phase; treatability study within a year	Total TPNA 50mg/kg; PCPs 50 mg/kg; xylene 1.5 mg/kg; benzene 10 mg/kg; TCE .05 mg/kg; DCE .07 mg/kg	Land treatment
IV	Koppers* Florence, SC RCRA lead	Mike Arnet 404-347-7603 FTS 257-7603	Creosote, PCP, arsenic (CCA)/soil, groundwater	Treatability study to be conducted early 1991	Unknown	Land treatment
IV	Langdale Facility Sweetwater, TN RCRA lead	Charles Burroughs 615-741-3424	Creosote (K001 waste)/soils, sludges	Contaminated soil and sludge excavated; site capped after biotreatment	Not yet established	Land treatment using bacteria, nutrients, and cometabolite
IV	Shavers Farm* Shelby County, GA Removal lead	Chuck Eger 404-347-3931 FTS 257-3931	Dicamba, benzoic acid, dichlorosalicyclic acid, benzonitrile/soil	Pilot bench-scale treatability studies being reviewed; workplans in place, comments to go over 30 days	25 ppm for all contaminants	Undetermined
IV	Stallworth Timber* Beatrice, AL RCRA lead	Jason Darby 404-347-3433 FTS 257-3433	PCP, creosote/groundwater, soil	Assessing extent of contamination	Not yet established	Land treatment
IV	White House Waste* White House, FL Fund lead	Tony Best 404-347-2643 FTS 257-2643	Acids, PCB, waste oil, creosote/groundwater	Bench treatability study completed; risk assessment and treatability study ongoing	Not yet established	Possible bioremediation
V	Allied Chemical* Ironton, OH Enforcement lead	Jim Van der Kloot 312-353-9309 FTS 353-9309	PNAs/soil	Conducting pilot studies; ROD signed 12/90	1 ppm carcinogenic PAHs	In situ and prepared pad
V	Allied Signal/Bendix St. Joseph, MI PRP lead	John Kuhns FTS 353-6556	TCE, DCE, VC/groundwater	Pilot scale field demonstration scheduled for 3rd quarter 1991; pilot bench-scale tests have been completed off-site	Not yet established	In situ treatment using indigenous methanotrophs
V	Ariatech Chemicals Haverhill, OH RCRA lead	Jim Saric 312-886-0992	Cumene, phenols/soil, groundwater	Conducting treatability studies	4.1 mg/kg phenol 4.67 mg/kg cumene	Undetermined
V	B & F Trucking Company* Rochester, MN UST lead	Pat Hanson MPCA 612-643-3426	BTEX, gasoline/soil, groundwater	Currently conducting bioremediation	Unknown	In-situ pump treatment; reinfiltration gallery
V	BP Oil Company Toledo, OH UST lead	Stephen Bouchard 312-886-7569	Petroleum/soil	Discussing bioremediation as an option; no studies underway	Not yet established	Land treatment
V	BP Oil Company* Lima, OH	Don Heller 312-353-1248	Petroleum/soil	Discussing bioremediation as an option; no studies underway	Not yet established	Land treatment
V	Burlington Northern, MN* State/Federal lead (split lead)	Amy Blumberg 312-353-9308 MPCA contact: J. Todd Goeks 612-296-7710	Creosote/soil	Currently conducting bioremediation; ROD signed 6/4/86	Groundwater: 28 mg/l carcinogens; 300 mg/l non-carcinogens Soil: detoxification levels	In situ
V	Cliff/Dow Dump, MI PRP lead	Lida Tan 312-886-1842	Wood tar, acetic acid, phenol, benzene, PAHs	Conducted treatability studies; currently in pre-design stage	Not yet established	Forced aeration
V	Duell and Gardner* Muskegan, MI Fund lead	Karla Johnson 312-886-5993	Volatiles, semi-volatiles, PCBs and/or inorganic metals/soil, groundwater	Conducting treatability studies	Not yet established	Undetermined
V	Fisher-Calo LaPorte, IN Lead pending (probably PRP)	Brad Bradley 312-886-4742	TCE, DCE, DCA, PCBs/soil, groundwater	ROD signed 8/7/90; currently in design stage	5 ppb TCE; 70 ppb DCE; 200 ppb DCE; drinking water standards used where possible	Undetermined

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CERCLA/RCRA/UST SITES CONSIDERING, PLANNING, OR OPERATING FULL-SCALE BIOREMEDIATION SYSTEMS

Rgn	Site/Location/Lead	Contact/Phone Number	Contaminants/Media	Status	Clean-up Levels	Treatment
V	Galesburg/Koppers, IL* State lead	Brad Bradley 312-886-4742	Phenols, chlorophenol, PNAs, PCP, PAHs/soil	Conducting pilot study; ROD signed 7/89; have not yet started design phase	Not yet established	Land treatment; in situ with amendments - amendments and applications not yet determined
V	Hentchels* Travers City, MI UST lead	Bob Kettner 616-775-9728	Gasoline/soil, groundwater	Bioremediation activity ended; some contamination remains; Agency requested further cleanup	Non-detection levels	Air sparging; nutrient addition; in situ pump and reinfiltration gallery
V	Joslyn MFG, MN* State enforcement lead	Cliff Twaroski 612-296-7827	PAHs, PCP, dioxin, furans/soil	MN declaration 1988 - no concurrence by EPA; design completed	150 ppm total PAHs; 100 ppm total PCP	Land treatment using irrigation and addition of nutrients and microbes
V	Marathon Station Kentwood, MI UST lead	Bonnie White 616-456-5071	gasoline/groundwater	Conducting bioremediation	Background non-detection levels or risk-based levels	Fixed film bioreactor with submerged plate
V	Mayville Fire Department Mayville, MI UST lead	Sue Kaelber Matlock 517-771-1731	BTEX/soil, groundwater	Conducting bioremediation	Groundwater: 1 ppb BETX Soil: 10 ppb BETX	Bioremediation using oxygen with no addition of nutrients
V	McGillis Gibb, MN* Fund lead	Darryl Owens 312-886-7089	PAHs, PCP/groundwater	Treatability and pilot studies completed 12/89; report due 3/91	Not yet established	Fixed film aerobic reactor
V	Moss American Milwaukee, WI Fund lead	Betty Lavs 312-886-4784	PAHs/soil, sediments	Pilot study completed; ROD signed 9/27/90; design stage Summer 1991	6.1 ppm PAHs	Slurry bioreactor using indigenous bactena
V	New Lyme, OH Fund lead	Darryl Owens 312-886-7089	Ethyl benzene; methylene chloride; phthalates/groundwater	Conducted pilot study 1/88; final process to begin operation by 11/90	68 ug/l ethyl benzene; 473 ug/l methylene chloride; 9.2 ug/l phthalate	Rotating biological reactors
V	Organic Chemical, MI Fund lead	Tom Williams 312-886-6157	Oil, TCE, toluene/groundwater	Waiting for feasibility study to do remediation on TCE and toluene; working on additional workplan for oil	Not yet established	Undetermined
V	Parke-Davis Holland, MI RCRA lead	Dave Petrovski 312-886-0997	Benzene, methanol, isopropenol, fuel/soil, groundwater	Approaching design phase	Not yet established	Undetermined
V	Reilly Tar, IN* Enforcement lead	Dion Novak 312-886-4737	Creosote, PAHs, metals, semi VOAs/soil; benzene, ammonia, pyridine/groundwater	RI completed; draft treatability study workplan under review	Not yet established	Undetermined
V	Reilly Tar & Chemical* St. Louis Park, MN Enforcement lead	Darryl Owens 312-886-7089 MPCA contacts: Doug Beckwith 612-296-7301 Mike Scott 612-296-7297	Creosote, PAHs/soil, groundwater	Planning treatability study	Not yet established	In situ (surface and subsurface) using additional nutrients (N, P)
V	Seymour Recycling, IN* Unit 1 PRP lead	Jeff Gore 312-886-6552	VC, TCE, DCE/groundwater	Preliminary stages; ROD signed 9/87	Drinking water standards	Proposed bioremediation of tetrahydrofurans in groundwater
V	Seymour Recycling, IN Unit 2 PRP lead	Jeff Gore 312-886-6552	VC, TCE, DCE/soil	ROD signed 9/87; bioremediation of soil completed; no treatability studies conducted	None established	Biodegredation of heavy volatiles hydrocarbons and non-volatiles
V	Sheboygan River and Harbor* Sheboygan, WI PRP lead	Bonnie Eleder 312-886-4885	PCBs/sediment	Treatability and pilot studies to be completed end of 1991;	Not yet established	Natural and enhanced biodegredation in enclosed facility; in situ study in capped sediments

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CERCLA/RCRA/UST SITES CONSIDERING, PLANNING, OR OPERATING FULL-SCALE BIOREMEDIATION SYSTEMS

Rgn	Site/Location/Lead	Number	Contact/Phone Contaminants/Media	Status	Clean-up Levels	Treatment
V	Sleeping Bear Dunes National Lakeshore UST lead	Phil Durgin 702-798-2100 John Wilson 405-332-8800	Gasoline/groundwater	Site investigation completed	Not yet established	Natural biodegredation - no amendments
V	St. Louis River, MN State lead	Debbie Siebers 312-353-9299 Cliff Twaroski 612-296-7827	PAHs/soils, sediments	Planning treatability study	Not yet established	Undetermined
V	Union Carbide, OH* Enforcement	Kathleen Warren 312-353-6756	VOCs, dioxin, mono-dichlorinated biphenyls/soil, groundwater	Remedial investigation completed	Not yet established	Undetermined
VI	Atchinson* Santa Fe, NM Enforcement lead	Susan Webster 214-655-6730 FTS 255-6730	Hydrocarbons, diesel/soil	Some treatability studies completed; ROD signed 9/23/88; planning pilot project; starting in situ 6/91	Not yet established	In situ (surface and subsurface); sludges treated separately
VI	French Limited Crosby, TX	Judy Black 214-655-6735 FTS 255-6735	Benzene, vinyl chloride, DCE, PCBs/sludges, soil, and groundwater	ROD signed 3/88; project under design	Soils and sludges: BAP 9 ppm; PCB 23 ppm; VOCs 43 ppm; arsenic 7 ppm; benzene 14ppm; Groundwater: MCLs	Treatment in a lagoon for sludges and soils; pump and treat and/or in situ for groundwater
VI	Hudson Refining Co.* Cushing, OK RCRA lead	Keith Phillips 214-655-6480 FTS 255-6480	Oil, grease, PAHs/soil, groundwater	Operational since 4/88	Varied	Three phases of land application with varied applications of nutrients: 1) active - requires monthly application of nutrients and monthly tilling; 2) enhanced - annual application of nutrients and no tilling; and 3) augmented - no addition of nutrients or tilling
VI	North Cavalcade* Houston, TX State lead	Deborah Griswold 214-655-6715 FTS 255-6715	Carcinogenic PAHs, benzene/groundwater; carcinogenic PAHs/soil	Design stage; planning bioremediation pilot project for FY91	.04 ppm benzene; 1 ppm carcinogenic PAHs	Groundwater: pump and carbon adsorption treatment Soil: bioremediation method - specifics undetermined
VI	Old Inger* Darrow, LA Fund lead	Paul Sierminski 214-655-6710 FTS 255-6710	Hydrocarbons/soil, groundwater	Pilot studies completed; ROD signed 9/84; design completed 1986; finalizing construction with remediation to begin 9/91; supplemental groundwater RI being conducted		Land treatment
VI	Sheridan Disposal Services* Houston, TX Enforcement lead	Ruth Izraeli 214-655-6735 FTS 255-6735	Benzene, toluene, ethyl benzene, phenols, PCBs/soil, sludge, surface water	Beginning pilot study; ROD signed 12/88; currently in design stage	PCBs as an indicator of other organics (25 ppm PCBs)	Aqueous bioreactor
VII	Amoco Refinery* Sugar Creek, MO RCRA lead	Frank Dolan 314-751-3178	Oil, PAHs, refinery sludges, metals/sludges, soil	Treatability studies completed 1988-89; treatment facility on-line since 7/90	Less than 300 mg/kg total PAHs; less than 160 mg/kg potentially carcinogenic PAHs	Land treatment and liquid solids reactor
VII	Conservation Chemical Kansas City, MO Enforcement lead	Steve Auchterlonie 913-551-7778 FTS 276-7778	Phenols/groundwater	Treatability study conducted; ROD signed 9/30/87; operational since 4/90	MO drinking water standards	Fixed film bioreactor (2 in series)
VII	Fairfield Coal & Gas▲ Fairfield, IA Enforcement lead	Steve Jones 913-551-7755 FTS 276-7755	Benzene, ethyl benzene, toluene, xylene, PAHs/groundwater	RD phase	Benzene 1 ppb; carcinogenic PAHs 0.2 ppb	In situ (subsurface) using nutrient enhancement

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Rgn	Site/Location/Lead	Number	Contact/Phone Contaminants/Media	Status	Clean-up Levels	Treatment
VII	International Paper* Joplin, MO Unit 1 RCRA lead	Frank Dolan 314-751-3176	24 organic constituents from creosote, including PAHs, PCP/soil	Under construction; pilot studies to be conducted concurrently with treatment operations	Sum of the concentrations of 24 aromatic compound is less than 600 ppm	Land treatment (covered facility)
VII	International Paper* Joplin, MO Unit 2 RCRA lead	Frank Dolan 314-751-3176	24 organic constituents from creosote, including PAHs, PCP/soil	Under construction; pilot studies to be conducted concurrently with treatment operations	Not yet determined	Land treatment (covered facility)
VII	International Paper* Joplin, MO Unit 3 RCRA lead	Frank Dolan 314-751-3176	24 organic constituents from creosote, including PAHs, PCP/soil	Under construction; pilot studies to be conducted concurrently with treatment operations	Not yet determined	Land treatment (covered facility)
VII	International Paper* Joplin, MO Unit 4 RCRA lead	Frank Dolan 317-751-3176	24 organic constituents from creosote, including PAHs, PCP/soil	Under construction; pilot studies to be conducted concurrently with treatment operations	Not yet determined	Land treatment (covered facility)
VII	Park City, Kansas▲	John Wilson RSKERL 405-332-8800 FTS 743-2259	Refined petroleum products/water table aquifer in a municipal well field	Full scale cleanup will start 3/91	Drinking water standards for benzene	Subsurface treatment using nitrate as electron acceptor
VII	Scott Lumber* Alton, MO Removal lead	Bruce Morrison 913-236-3881 FTS 757-3881	Creosote compounds(PAHs, benzo-a-pyrene)/soil (no PCP)	Conducted treatability study 1988, operational since 6/89; 9,200 tons of soil treated	500 ppm total PAHs, 14 ppm benzo-a-pyrene	Land treatment using irrigation, no nutrient addition
VII	Vogel Paint & Wax, IA* State lead	Steve Jones 913-551-7755 FTS 276-7755	Benzene, ethyl benzene, xylene, toluene, MEK/soil	Bench-scale studies complete; ROD signed 9/89; design complete, currently in RA phase	TCLP test for leachwater organics; 100 mg/kg organic hydrocarbons, EPA toxicity test	Land treatment
VIII	Burlington Northern Somers, MT Enforcement lead	Jim Harris 406-449-5414 FTS 585-5414	PAHs, zinc, phenol/soil, sediments, groundwater	Land treatment demonstration 11/90; pilot studies planned for groundwater in 11/90; ROD signed 9/27/89; full scale 1992	Soil. 36 mg/kg carcinogenic PAHs; Groundwater 030 ug/l carcinogenic PAHs	Soils: land treatment Groundwater and sediments: in situ
VIII	Chemical Distribution Site* Billings, MT State lead	Jim Morrison ECOVA 206-883-1900	Herbicides (chlorinated phenol)/groundwater	Operational since 4/88	5 ppm 2,4-D	In situ (subsurface, using nutrients and oxygen)
VIII	Libby Groundwater Site Libby, MT Enforcement lead	Julie Dalsoglio 406-449-5414 FTS 585-5414	PAHs, PCPs/soil, groundwater	ROD signed 12/88; consent decree 10/89; bench-scale demonstration project for land treatment unit, bioreactor and in situ treatment completed; full-scale remedial action to begin Summer 1991	Soil· 88 mg/kg total carcinogenic PAHs; 8 ppm non-carcinogenic PAHs; 7.3 ppm pyrene; 37 mg/kg PCP; 1 ppb dioxin; 8 mg/kg napthalene; 8 mg/kg phenanthrene; 7 3 mg/kg pyrene Groundwater· 400 ug/l carcinogenic PAHs, 40 ug/l non carcinogenic PAHs, 1 05 mg/l PCP, 5 mg/l benzene, 50 mg/l arsenic; other compounds not greater than 10^{-4}	Soil land treatment Groundwater: in situ treatment of groundwater in fixed film bioreactor
VIII	Pesticide Distribution Facility Minot, ND RCRA lead	Jim Morrison ECOVA 206-883-1900	Pesticides (2,4-D)/soil	Full-scale bioremediation completed 1988	5 ppm 2,4-D	Above ground and slurry phase biotreatment
VIII	Public Service Denver, CO UST lead	Suzanne Roll 303-293-1511	Benzene, xylene, toluene/soil, groundwater	Operating unit for one year	Not yet established	

▲ Indicates a new site in the Table
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Shading depicts a non-CERCLA site.

CERCLA/RCRA/UST SITES CONSIDERING, PLANNING, OR OPERATING FULL-SCALE BIOREMEDIATION SYSTEMS

Rgn	Site/Location/Lead	Contact/Phone Number	Contaminants/Media	Status	Clean-up Levels	Treatment
VIII	Union Pacific Laramie, WY CERCLA/RCRA enforcement lead	Felix Fleches 303-330-1524 FTS 330-1524	Creosote, PCP/soil, groundwater	Treatability and pilot studies completed 9/90	Based on human health or agricultural standards, whichever is more stringent (to be decided in next 6 months)	Undetermined
IX	BKK Landfill* West Covina, CA Enforcement Lead	Carmen Santos 415-744-2144	Arsenic, cadmium, chromium, lead, mercury, dichloromethane, chloroform, 1-2 dichloropropane, carbon tetrachloride, TCE, benzene, phenol, toluene, cyanide, heavy metals/groundwater	Remedial study still in progress; full-scale bioremediation in operation since 1987	.1 ppm cadmium; .05 ppm chromium, lead, arsenic; .002 ppm mercury; heavy metals 1.5 ppm; 150 ppb dichloromethane, chloroform, TCE; 700 ppb 1-2 dichloropropane; 5 ppb carbon tetrachloride; 550 ppb benzene; not established for phenols, toluene and cyanide (total VOCs 2 ppm)	Bioreactor - leachate treatment plant with metal removal system using complexation with EDTA
IX	CALTRANS Lakeport & Garberville, CA CA lead	Ken Smarkel CA Dept. of Health Svcs 916-322-3910	Oil/soil	Field work began 11/8/88; bioremediation completed	Approximately 100 ppm total petroleum hydrocarbons	Land treatment
IX	Citrus Heights Irrigation Citrus Heights, CA PRP lead	Ken Smarkel CA Dept. of Health Svcs 916-322-3910	Diesel fuel/soil	Bioremediation completed	Approximately 100 ppm total petroleum hydrocarbons	Bioreactor
IX	Converse* Montebello Corp. Yard Montebello, CA	Paul Hadley CA Dept. of Health Svcs. 916-322-3823	Gasoline/soil	Conceptual workplan submitted for review	Not yet determined	In situ bioremediation of contaminated soil; moisture/nutrient addition controlled and monitored in the subsurface; oxygen supplied via vacuum wells
IX	CWX Freight Lines* Santa Rosa, CA CA lead	Mark Berscheid CA Dept. of Health Svcs. 916-322-3294	Diesel fuel/soil	No treatability studies conducted; demonstration started 10/22/90; pre-treatment samples completed resulting in non-detect	Not yet determined	Sprinkler system to apply bioculture formulation; collected leachate treated in an aerobic biological reactor before recirculation
IX	Equipment Manufacturer* San Francisco, CA RCRA lead	Jim Morrison ECOVA 206-883-1900	Diesel fuel/soil	Remediation completed 1988; 17,000 cubic yards of soil treated	100 ppm TPH in soil	Above-ground biological treatment; solid phase biological treatment
IX	Food Processor Ripon, CA CA lead	Jim Morrison ECOVA 206-883-1900	TCE/soil, groundwater	Pilot studies completed; currently in design stage	.5 ppb TCE in groundwater	In situ biological treatment with above-ground bioreactor
IX	Former Service Station▲ Los Angeles, CA State lead	Tony Palagyi 818-505-2701	Petroleum hydrocarbons/soil, groundwater	Remediation complete	100 ppm TPH in soil; drinking water standards	In situ bioremediation, closed loop system; hydrogen peroxide as oxygen source; above ground holding tank for nutrient addition
IX	Former Tank Farm* Torrance, CA CA lead	Jim Morrison ECOVA 206-883-1900	Petroleum hydrocarbons/soil	Treatment completed 1/91; 300,000 cubic yards of soil treated	1,000 ppm total petroleum hydrocarbons	Above ground biological treatment
IX	Fort Ord Army Base* Monterey, CA Federal facility enforcement lead	Jim Chesnutt 415-744-2389 Vance Fong 415-744-2392	MEK, VOCs/soil, groundwater	Bioremediation currently being used as an interim measure; pilot testing completed; moving into ROD phase	Not yet established for soil; MCLs for groundwater	Pump and treat carbon adsorption for groundwater, followed by land treatment for MEK

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CERCLA/RCRA/UST SITES CONSIDERING, PLANNING, OR OPERATING FULL-SCALE BIOREMEDIATION SYSTEMS

Rgn	Site/Location/Lead	Contact/Phone Number	Contaminants/Media	Status	Clean-up Levels	Treatment
IX	Growers Air Service* UC Davis Medlock Field Woodland, CA State lead	John Wasnousky CA Dept of Health Svcs. 916-322-2643	Pesticides: atrazine, BRAVO chlorothalonil, dacthal, thiadine I and II, DDT, thiadine sulfate, trifluralin, methyl parathion, malathion, parathion, methyl trithion, thion, thithion, paraxon/soil	Bioremediation completed - report available	Not yet determined	In situ with addition of nutrients
IX	Harmon Field* Tulare County, CA State lead	Tony Luan CA Dept of Health Svcs 916-322-6872	10 organic pesticides/	Pilot project completed, evaluating field study results	Not yet determined	Land treatment
IX	Hercules Incorporated* Hercules, CA State lead	Tony Luan CA Dept of Health Svcs 916-322-6872	TNT, trinitrobenzene, DNT, nitrobenzene/soil	Pilot scale field study completed, evaluating field study results	30 ppm TNT, 5 ppm DNT, 5 ppm nitrobenzene	Land treatment
IX	JASCO* Mt View, CA Fund lead	Rose Marie Caraway 415-744-2235	VOCs/soil, groundwater	Final RI complete, FS due 3/1/91	Not yet established	Bioremediation or land treatment - composting
IX	J H Baxter* Weed, CA Enforcement lead	Mary Masters 415-744-2370 FTS 484-2370	Arsenic, chromium, PCP, PAHs, dioxins, furans/soil, sediments, groundwater, benzene/groundwater, zinc, TCP/sediments	Treatability studies conducted, ROD signed 9/27/90	Groundwater: arsenic 5 ppb, chromium 8 ppb, benzene 1 ppb, PCP 2 2 ppb; PAHs 5 ppb, dioxin 000025 ppb Surface soils: arsenic 8 ppm, chromium 500 ppm, PCP 17 ppm, carcinogenic PAHs 51 ppm, dioxin 001 ppm, furans 001 ppm. Leachate: arsenic 5 ppm, chromium 5 ppm, PCP 1 7 ppm, carcinogenic PAHs 005 ppm, non-carcinogenic PAHs 15 ppm, dioxin 001 ppm. Sediments: arsenic 8 ppm, chromium 18 ppm, zinc 26 ppm, carcinogenic PAHs 5 ppm, PCP 1 ppm, TCP 1 ppm.	Land treatment for organics using imported microbes for soils and sediments (still unclear as to need to import microbes - indigenous microbes may work); cement fixation for inorganics in soils, bioreactor for organics in groundwater, chemical precipitation for inorganics in groundwater
IX	Koppers Oroville* Plant, CA Enforcement lead	Fred Schauffler 415-744-2365 FTS 484-2365	Arsenic, chromium, PCDD/PCDF, PAHs, PCP, creosote/soil, arsenic, chromium, PCDD/PCDF, PAHs, PCP/groundwater	ROD signed 9/89, currently in the last stage of the consent decree for RD/RA, treatability studies to be done late 1991	Background levels for arsenic soil and Cr in soil and groundwater, 007 ug/l PAHs in groundwater, 19 mg/kg in soil, PCP 17 mg/kg in soil, 2 2 ug/l in groundwater, dioxin 30 ppt in soil, 0 53 ppq in groundwater	In situ bioremediation of soil with PCP, soil washing for soil with PAHs, fixation of metal conaminated soil, groundwater treatment with carbon
IX	Liquid Gold* Richmond, CA State lead	Rose Marie Caraway 415-744-2235	Waste oils, metals (lead, zinc, phenol)/soil, groundwater	Second phase of feasibility study completed, RI approved by State lead agency	Not yet established	Undetermined
IX	Montrose Chemical Corp of California* Torrance, CA Enforcement lead	Johanna Miller 415-744-2404	DDT, monochlorobenzene/soil, groundwater	Bench-scale treatability study on soil and groundwater completed 8/90, currently planning follow-up bench-scale study for groundwater only, bench-scale study proved not effective for DDT	Not yet established	In situ enhanced by injection of nutrients
IX	Naval Civil Engineering Laboratory Port Hueneme, CA	Tej Pahwa CA Dept. of Health Svcs 916-322-2224	Jet fuel, gasoline, diesel fuel, transmission fluid, aviation fluid/soil, groundwater	Bench scale tests completed in 10/89; final consultant report submitted to Navy for approval; pilot tests are being planned; working on pilot design	Not yet determined	Hydrocarbon aeration
IX	Oil Co. Visalia, CA CA lead	Jim Morrison ECOVA 206-883-1900	Petroleum, hydrocarbons/soil	Conducting full-scale bioremediation	5 ppm TPH in groundwater	In situ

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CERCLA/RCRA/UST SITES CONSIDERING, PLANNING, OR OPERATING FULL-SCALE BIOREMEDIATION SYSTEMS

Rgn	Site/Location/Lead	Contact/Phone Number	Contaminants/Media	Status	Clean-up Levels	Treatment
IX	Protek Carson City, CA PRP lead	Ken Smarkel CA Dept. of Health Svcs. 916-322-3910	Diesel fuel/soil	Bioremediation completed	Approximately 100 ppm total petroleum hydrocarbons	Land treatment
IX	Refinery Los Angeles, CA CA lead	Jim Morrison ECOVA 206-883-1900	Petroleum, hydrocarbons/soil	Conducting full-scale bioremediation	10,000 ppm TPH in soil	In situ
IX	Romic Chemicals* E. Palo Alto, CA RCRA lead	Jesse Beaks 415-744-2036 FTS 484-2036	MEK, VOCs/soil, groundwater; DCE/surface water	Treatability studies planned for end of FY91; now in investigation stage	Not yet determined	In situ, possibly pump and treat
IX	San Diego Gas and Electric* Main Street Facility San Diego, CA PRP lead	Paul Hadley CA Dept. of Health Svcs. 916-322-3823	Petroleum fuels/soil, groundwater	Project is underway; monitoring is ongoing	Not yet established	In situ
IX	Seaside High School* Seaside, CA	Dick Erickson CA Dept. of Health Svcs. 916-322-7046 Alan Ingham 916-322-5629	Diesel fuel/soil	Bioremediation completed 1988	500 ppm hydrocarbons in soil	Land treatment
IX	SEGS Solar Project* Kramer Junction, CA CA lead	Bruce La Belle CA Dept. of Health Svcs. 916-324-2958	Heat transfer fluid (biphenyl, diphenyl ether)/soil	Pilot test completed; full scale field work began 7/90; periodic site visits will be used to oversee/monitor progress	1,000 ppm total biphenyl and diphenyl ether	Waste pile treatment using added nutrients, water and tilling
IX	Southern California Edison* Visalia, CA State lead	Dave Roberts 415-744-2227	PCP, VOCs/groundwater	RI/FS currently in progress for groundwater	Not yet established	Undetermined - bioremediation possible
IX	Southern Pacific Transportation Co * SPTC Maintenance Yard Roseville, CA State lead	David Wright CA Dept of Health Svcs. 916-332-3910	Hydrocarbons, diesel fuel/soil	Treatment completed 1/31/91	5,000 ppm hydrocarbons	Land treatment - nutrients added to contaminated soil to enhance biological degradation
IX	Studio Hollywood, CA State lead	Jim Morrison ECOVA 206-883-1900	Petroleum, hydrocarbons/soil, groundwater	Conducting full-scale bioremediation	Drinking water standards	In situ
X	American Crossarm* Fund lead	Lee Marshall 206-553-2723	PCP/soil	Currently conducting remedial investigation	Not yet established	Undetermined
X	Former Oil Storage Terminal* Seattle, WA UST lead	Jim Morrison ECOVA 206-883-1900	Petroleum hydrocarbons/soil, groundwater	Full-scale bioremediation ongoing until 1992; 100,000 cubic yards of soil being treated	Soil: 200 ppm petroleum hydrocarbons Groundwater: 5 ppb benzene	In situ and above ground biological treatment
X	Former PCP Blending Facility* Portland, OR RCRA lead	Jim Morrison ECOVA 206-883-1900	PCP/soil	Full-scale bioremediation ongoing since 1988	To be established in 1991	Slurry phase bioreactor
X	Former Service Station▲ Vancouver, WA State Lead	Jim Morrison ECOVA 206-883-1900	Diesel fuel	Treatment complete 6/89, 1,000 cubic yards of soil treated	200 ppm in soil	Above ground biological treatment

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CERCLA/RCRA/UST SITES CONSIDERING, PLANNING, OR OPERATING FULL-SCALE BIOREMEDIATION SYSTEMS

Rgn	Site/Location/Lead	Contact/Phone Number	Contaminants/Media	Status	Clean-up Levels	Treatment
X	School Distnct Maintenance Facilities▲ Seattle, WA *State lead*	Jim Morrison ECOVA 206-883-1900	Diesel fuel	Treatment ongoing until 6/91, 2,000 cubic yards of soil treated	200 ppm in soil	Above ground biological treatment
X	Utah Power and Light* Idaho Falls, ID State lead	Andrew Pentony 208-334-5879	Creosote/soil phenols/groundwater	Final plan for bioremediation not yet submitted	50 ppb creosote in soil, EPA Region 10 groundwater protection standards for groundwater	Part of upgradient portion not capped - bioremediation being used (white rot fungus)
X	Wyckoff* Eagle Harbor, Puget Sound, WA PRP lead	Rene Fuentes 206-553-1599 FTS 399-1599	Creosote, PCP/soil, groundwater, surface water	RI/FS not conducted yet	Not yet established	Bioreactor - activated sludge for treatment of groundwater, possible soil and sludge bioremediation

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Bioremediation Field Initiative Contacts

If you have information on a site using bioremediation that is not identified in Table 1, please submit this information in writing to Nancy Dean at TIO. Additionally, if you have laboratory-, pilot- or full-scale treatability data on a site, please have a copy sent to TIO at the address listed below.

Fran Kremer
Coordinator, Bioremediation Field Initiative
U.S. Environmental Protection Agency
Center for Environmental Research Information (CERI)
26 W. Martin Luther King Drive
Cincinnati, OH 45268

Nancy Dean
Technology Innovation Office (TIO)
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response (OSWER)
Mail Code: OS-110
401 M Street, S.W.
Washington, D.C. 20460

Upcoming Conference/Publications

Biotechnology for Wastewater Treatment - Conference sponsored by the American Chemical Society National Meeting. April 14-19, 1991. Atlanta, GA. Contact: Rakesh Govind, University of Cinncinati, Department of Chemical Engineering, 697 Rhodes Hall (ML 171), Cincinnati, OH 45221-0171, (513) 556-2761.

Microbial Processes in the Degradation of Groundwater Contamination - Short Course. June 18-20, 1991. Tampa, FL. Contact: The Association of Ground Water Scientists and Engineers, division of the National Water Well Association, 6375 Riverside Drive, Dublin, OH 43017, (614) 761-1711.

Proceedings available from **Bioremediation: Fundamentals and Effective Application** - Symposium, February 21-22, 1991. Lamar University, Beaumont, TX. $35.00/complete papers in proceedings. Contact: Tom Pinson, (409) 880-8768.

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SUPERFUND TECHNICAL SUPPORT PROGRAM (TSP)

The Superfund Technical Support Program has been designed to facilitate communication and coordination between EPA's Superfund site managers (On Scene Coordinators-OSCs and Remedial Project Managers-RPMs) and EPA Headquarters, Regions, State environmental agencies and the EPA Office of Research and Development. The purpose of the TSP is to ensure the consistent application of remedial technologies and the timely transfer of pertinant technical information. Through the program, EPA has established a network of technical support resources available to EPA's OSCs and RPMs that includes six technical Support Centers and two Forum Representatives from each Region, one in the area of ground-water fate and transport and the other in engineering/treatment. Technical experts participating in the TSP can assist field personnel with several different types of technical projects:

- *Evaluations of the feasibility of technologies as treatment options;*
- *Feasibility study reviews or workplan evaluations;*
- *Remedial design reviews;*
- *Implementation of treatability studies;*
- *Development or review of sampling plans; and*
- *Analysis of operational data.*

For immediate assistance on technical questions, RPMs and OSCs can call one of the six Support Centers:

- *Ground-Water Fate and Transport Center, Ada, Oklahoma;*
- *Monitoring and Site Characterization Center, Las Vegas, Nevada;*
- *Environmental Response Center, Edison, New Jersey;*
- *Exposure and Ecorisk Assessment Center, Athens, Georgia;*
- *Engineering and Treatment Center, Cincinnati, Ohio; and*
- *Health and Risk Assessment, Cincinnati, Ohio.*

To request on-site assistance or to initiate a technical assistance project, OSC's or RPM's should contact their Regional Forum representative. For projects requiring funding, written requests must be submitted to the appropriate Support Center. For further information on activities of the Regional Forums or the TSP call Rich Steimle at FTS: 382-7914 or 202/382-7914.

United States
Environmental Protection
Agency

Center for Environmental Research
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Cincinnati, OH 45268

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EPA

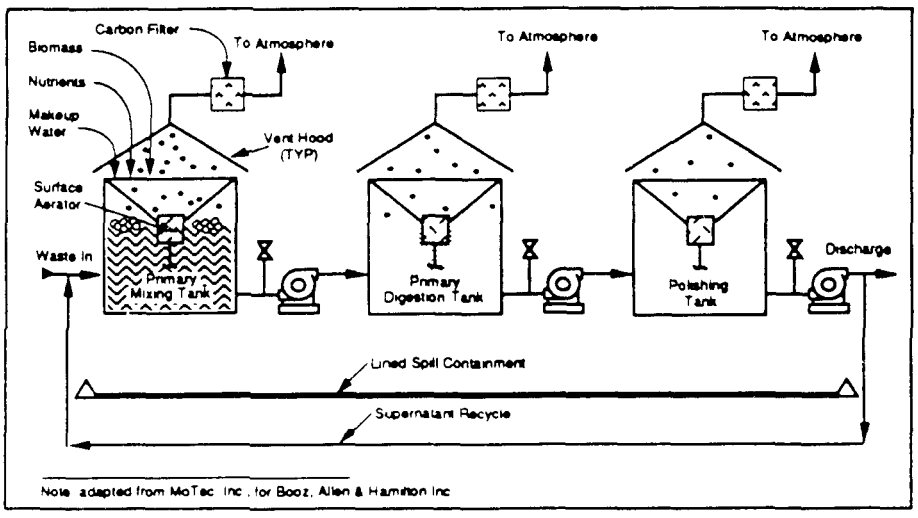
Innovative Technology

Slurry-Phase Biodegradation

TECHNOLOGY DESCRIPTION

Slurry-Phase Biodegradation (SPB) is potentially effective in treating various organic contaminants. It involves the commingling of excavated contaminated soil and sludge with bioactive microorganisms in a mobile batch reactor or an in-ground reactor. A typical treatment facility is shown in Figure 1.

Figure 1: Schematic Diagram of a Typical Slurry-Phase Biodegradation Treatment Facility



Note: adapted from MoTec Inc., for Booz, Allen & Hamilton Inc.

Prior to treatment, large-grained constituents such as stones and rubble are physically removed from the waste. The remaining waste is mixed with water to create the desired slurry composition (50 weight percent solids maximum). The slurry water may be contaminated ground water, surface water, or another water source that is brought on-site. The slurry is then mechanically agitated in a reactor chamber which creates and maintains the appropriate ambient environmental conditions (e.g., nutrient supply, temperature range, oxygen content, and pH level) needed for maximum bio-oxidation of the target contaminants. Microorganisms may be added initially to seed the reactor and/or added continuously during treatment to maintain the appropriate biomass concentration. The residence time in the reactor varies with the soil or sludge matrix, the physical and chemical nature of the contaminants, contaminant concentrations, and the efficiency of the bio-oxidation reactions. Upon completion of the process, the slurry is dewatered and the treated soil is redeposited on-site.

Advantages of SPB include the following: biodegradable organic compounds may be transformed into non-toxic compounds or mineralized; elaborate or sophisticated equipment is not required; and batch operation may allow more accurate mass-balance determinations. The major disadvantages are that the treatment time can be relatively slow and SPB is ineffective against inorganic wastes. Applications and limitations of the SPB technology are discussed below.

SITE CHARACTERISTICS AFFECTING TREATMENT FEASIBILITY

SPB has the potential to treat a wide range of contaminants such as pesticides, fuels, creosote, pentachlorophenol (PCP), polychlorinated biphenyls (PCBs), and some halogenated volatile organics. The projected effectiveness of this treatment on general contaminant groups is provided in Table 1.

Factors limiting treatment effectiveness include the inherent biodegradability of the target contaminant, dissolved oxygen content, operating temperature, soil/sludge characteristics, and the presence of reaction-inhibiting compounds such as heavy metals, chlorides, or even biodegradation by-products. Site-specific characteristics and their potential impact on the SPB process are listed in Table 2.

Variables governing the biodegradation process and resulting effectiveness can vary greatly between laboratory and actual field conditions. Therefore, in order to accurately model the effectiveness of SPB treatment, it is necessary to conduct bench- or pilot-scale tests at each site of interest.

Table 1
Effectiveness of Biodegradation Treatment on General Contaminant Groups for Soil and Debris

	Treatability Groups	Effectiveness
Organics	Halogenated volatiles	●
	Halogenated semi-volatiles	◒
	Non-halogenated volatiles	●
	Non-halogenated semi-volatiles	●
	PCBs	◒
	Pesticides	◒
	Dioxins/Furans	Insufficient Data
	Organic cyanides	X
	Organic corrosives	X
Inorganics	Volatile metals	X
	Non-volatile metals	X
	Asbestos	○
	Radioactive materials	X
	Inorganic corrosives	X
	Inorganic cyanides	X
Reactive	Oxidizers	X
	Reducers	X

● Demonstrated Effectiveness ◒ Potential Effectiveness ○ No Expected Effectiveness X Potentially Detrimental

Table 2
Site-Specific Characteristics and Impacts on Slurry-Phase Biodegradation Treatment

Characteristics Impacting Process Feasibility	Reasons for Potential Impact	Actions to Minimize Impacts
Variable waste composition	Inconsistent biodegradation caused by variation in biological activity	Dilution of waste stream
Water solubility	Contaminants with low solubility are harder to biodegrade	None; or longer exposure time to microorganisms
Biodegradability	Low biodegradability inhibits process	None; or longer exposure time to microorganisms; or co-metabolism with another compound; or dilution to nontoxic levels
Temperature outside 15° - 70°C range	Larger, more diverse microbial population present in this range	Temperature monitoring and adjustments
Nutrient deficiency	Lack of adequate nutrients for biological activity	Adjustment of the carbon/nitrogen/ phosphorus ratio
Oxygen deficiency	Lack of oxygen is rate limiting	Oxygen monitoring and adjustments
pH outside 4.8 - 8.5 range	Inhibition of biological activity	Sludge pH monitoring, addition of acidic or alkaline compounds
Microbial population	Insufficient population results in low biodegradation rates	Culture test, addition of culture strains
Water discharges and air emissions	Potential environmental and/or health impacts	Post treatment processes (e.g., air scrubbing, carbon filtration)
Nonuniform particle size	Waste mixtures must be of uniform particle size for proper slurry composition	Physical separation of large-grained particles
Presence of elevated levels of: • Heavy metals • Highly chlorinated organics • Some pesticides, herbicides • Inorganic salts	Can be highly toxic to microorganisms	Pretreatment processes (e.g., soil washing, precipitation) to remove constituents from or dilute them in the waste
Soil/sludge composition (i.e., clay, humus)	Clay and humus sorb contaminants more tightly	None; or pH adjustment or other chemical amendments

Table 3
Vendor Information

Company	Contact	Address
Ecova Corporation	Al Bourquin	3820 159th Street NE Redmond, WA 98052 (206) 883-1900
Detox Industries, Inc.	Joe Dailey	12919 Dairy Ashford Sugarland, TX 77478 (713) 240-0892
MoTec, Inc.	John R. Ryan	22419 72th Ave. South Kent, WA 98032 (206) 872-0247
Biotrol, Inc.	Debra Lindstrom	11 Peavey Road Chaska, MN 55318 (612) 448-2515

TECHNOLOGY CONSIDERATIONS

Some treatment limitations can be minimized by implementing pre- and post-treatment processes. For instance, wastes contaminated with heavy metals and high concentrations of volatile and semi-volatile organics can be initially treated prior to microbial degradation. Fugitive emissions of volatile organic compounds may also warrant further treatment (e.g., carbon adsorption). Acclimation of the microorganisms to the environment is waste/site specific and typically takes between 1 to 3 days. The standard reactor vessel requires an energy supply to run a 75 horsepower engine.

TECHNOLOGY STATUS

The following vendors claim to have successfully applied SPB to various media and waste types and presently possess the technology to conduct full-scale waste remediation:

- Ecova Corporation applied full-scale SPB at a hazardous waste site to treat contaminated sludges containing a combination of pesticide and chlorinated organic wastes. Further treatment information is not available. Ecova quotes the cost of a treatability test to be between $5,000 and $50,000, depending on the chemistry of the treatability groups.

- Detox Industries, Inc. applied pilot-scale SPB treatment to PCBs at a hazardous waste site in Herne, Texas. Approximately 0.75 tons of sludge containing 2,000 ppm PCBs were treated to less than 4 ppm (99.8 percent removal) within four months. Detox quotes the cost of a treatability test to be between $20,000 and $25,000. The estimated range for treatment costs is between $200 and $600 per cubic yard, depending on site-specific characteristics.

- MoTec, Inc. has applied full-scale SPB treatment to contaminated sludges at State-level uncontrolled hazardous waste sites containing high concentrations of PAHs and PCPs associated with wood treatment operations. They estimate the average half-life of the biodegradation process to be 90 days. MoTec quotes the average cost of a treatability study to be approximately $20,000.

Vendor names, contacts, and addresses can be found in Table 3. These vendors state that pilot- and full-scale SPB treatments have been demonstrated, selected and implemented at private and State sites. This technology has not yet been thoroughly demonstrated to the SITE program, possibly due to quality control and/or project management. SPB has been tentatively selected as a component of the source control remedy at the General Motors Superfund site in Massena, NY, where SPB will be applied to small volumes of PCB-contaminated oils contained in an undetermined number of tanks.

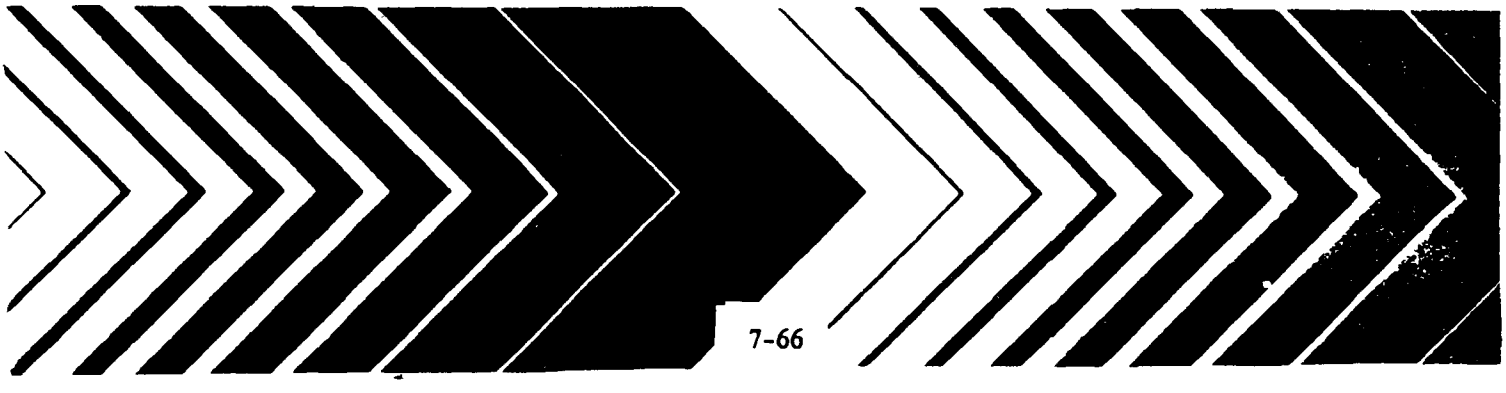
OFFICE OF RESEARCH AND DEVELOPMENT CONTACTS

More information concerning SPB may be obtained from Ron Lewis or Naomi Barkley, U.S. EPA, Risk Reduction Engineering Laboratory, Cincinnati, Ohio 45268, (513) 569-7856 or FTS 684-7856, and (513)569-7854 or FTS 684-7854, respectively.

Research and Development

EPA

Bioremediation of Contaminated Surface Soils



EPA-600/9-89/073

Bioremediation of Contaminated Surface Soils

J.L. Sims, R.C. Sims, and J.E. Matthews

August 1989

This report was developed by the
Robert S. Kerr Environmental Research Laboratory
U.S. EPA, ORD
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1. Introduction

Biological remediation of soils contaminated with organic chemicals is an alternative treatment technology that can often meet the goal of achieving a permanent clean-up remedy at hazardous waste sites, as encouraged by the U.S. Environmental Protection Agency (U.S. EPA) for implementation of The Superfund Amendments and Reauthorization Act (SARA) of 1986. Bioremediation is consistent with the philosophical thrust of SARA, for it involves the use of naturally occurring microorganisms to degrade and/or detoxify hazardous constituents in the soil at a contaminated site to protect public health and the environment. Bioremediation of contaminated soils, including applications and limitations, has been addressed at several recent scientific meetings and conferences [1, 2, 3, 4]. With regard specifically to wood preserving contaminated sites McGinnis et al. [5] have stated that reliable, safe, economical bioremediation techniques using soil systems are attractive and warrant thorough study and evaluation. The use of bioremediation techniques in conjunction with chemical and physical treatment processes, i.e., the use of a "treatment train," is an effective means for comprehensive site-specific remediation [6].

Wilson [7] identified biological processes, including microbial degradation, as a mechanism for attenuating contaminants during transit through the vadose zone to the groundwater. (The vadose zone is the region extending from the ground surface of the earth to the upper surface of the principal water-bearing formation [8]). On-site soil remedial measures using biological processes can reduce or eliminate groundwater contamination, thus reducing the need for extensive groundwater monitoring and treatment requirements [7, 9, 10]. Lehr [11] also emphasized that monitoring for attenuation of contaminants occurring in the vadose zone provides information for understanding their movement in and through the vadose zone and in the groundwater.

On-site bioremediation of contaminated soils generally is accomplished by using one of three types of systems:

(1) In situ;
(2) Prepared bed; or
(3) Bioreactor (e.g., slurry reactors) systems.

This discussion focuses on in situ and prepared bed systems, which utilize the soil as the treatment medium, as contrasted to bioreactor systems, in which contaminated soil is treated in an aqueous medium.

An in situ system consists of treating contaminated soil in place. Contaminated soil is not moved from the site. In general, naturally occurring microorganisms are allowed to treat the contaminants. Treatment often may be enhanced by a variety of physical/chemical methods, such as fertilization, tilling, soil pH adjustment, moisture control, etc. In some instances, addition of supplemental populations of adapted organisms may serve to enhance treatment.

In a prepared bed system, the contaminated soil may be either (1) physically moved from its original site to a newly prepared area, which has been designed to enhance bioremediation and/or to prevent transport of contaminants from the site; or (2) removed from the site to a storage area while the original location is prepared for use, then returned to the bed, where the treatment is accomplished. Preparation of the bed may consist of such activities as placement of a clay or plastic liner to retard transport of contaminants from the site, or addition of uncontaminated soil to provide additional treatment medium. Treatment may also be enhanced with physical/chemical methods, as with in situ systems.

2. Overview of Soil Biodegradation and Other Soil Processes

Bioremediation of a soil contaminated with organic chemicals is accomplished by degradation of specific organic constituents, i.e., the "parent" compounds. The term degradation may refer to complete mineralization of the constituents to carbon dioxide, water, inorganic compounds, and cell protein. The ultimate products of aerobic metabolism are carbon dioxide and water. However, biodegradation of a compound is frequently a stepwise process involving many enzymes and many species of organisms. Therefore, in the natural environment, a constituent may not be completely degraded, but only transformed to intermediate product(s) that may be less, equally, or more hazardous than the parent compound, as well as more or less mobile in the environment. Under anaerobic conditions (i.e., in the absence of oxygen), metabolic activities result in the formation of incompletely oxidized simple organic substances such as organic acids as well as other products such as methane or hydrogen gas.

The goal of on-site bioremediation is degradation that results in detoxification of a parent compound to a product or product(s) that are no longer hazardous to human health and/or the environment. Information on degradation and detoxification of a parent compound may be obtained using chemical and bioassay analyses [12, 13, 14]. Chemical analysis and identification of intermediate products may yield information about biochemical degradation pathways

and products, but are often time consuming and expensive. Bioassays may be used to demonstrate detoxification of parent compounds and are usually less expensive and time consuming. Before bioremediation is implemented at a contaminated site, degradation pathways for specific constituents present and/or detoxification demonstrations require investigation to ensure that environmental and health protection can be achieved.

Degradation of most organic compounds in soil systems may be described by monitoring their disappearance in a soil through time. Disappearance, or rate of degradation, is often expressed as a function of the concentration of one or more of the constituents being degraded. This is termed the order of the reaction and is the value of the exponential used to describe the reaction [15]. Either zero or first order power rate models are often used in environmental studies.

Zero order reactions are ones in which the rate of transformation of an organic constituent is unaffected by changes in the constituent concentration because the reaction rate is determined by some other factor than the constituent concentration. If a constituent C is transformed to X, the rate of change of C is:

$$dC/dt = -k \quad (1)$$

On integration, the equation becomes:

$$C_t = C_o - kt \quad (2)$$

where C_t = concentration of constituent remaining at time t; C_o = initial concentration of constituent; and k = zero order rate constant. A useful term to describe the reaction kinetics is the half-life, $t_{1/2}$ which is the time required to transform 50% of the initial constituent:

$$C_t = C_o/2, \text{ then } t_{1/2} = C_o/2k \quad (3)$$

The first order rate model (Equation 4) is widely used because of its effectiveness in describing observed results as well as its inherent simplicity. Its use also allows comparison of results obtained from different studies. In a first order rate reaction, the rate of transformation of a constituent is proportional to the constituent concentration:

$$dC/dt = -kC \quad (4)$$

where C = contaminant concentration (mass/mass); t = time; and k = first order rate constant (1/time). After integration of Equation 4 and rearrangement of the integrated equation, Equation 5 may be used to graphically determine the rate constant, k:

$$\ln(C_t/C_o) = -kt \quad (5)$$

where C_t = concentration of constituent remaining at time t; and C_o = initial concentration of constituent. A plot of $\ln(C_t/C_o)$ versus t is linear with a slope of -k. The rate constant k is independent of the concentration of constituent, since the slope is constant over time. To calculate the time required to transform one-half of the initial constituent ($C_t = C/2$), the following equation is used:

$$\ln((C_o/2)/C_o) = -kt_{1/2} \quad (6)$$

which is equal to:

$$t_{1/2} = 0.693/k \quad (7)$$

where $t_{1/2}$ = half-life of the constituent.

First order kinetics generally apply when the concentration of the compound being degraded is low relative to the biological activity in the soil. However, very low concentrations may be insufficient to initiate enzyme induction or support maintenance requirements necessary for microbial growth, even if the compound can be used as an energy source [16].

A second model used to describe degradation in soils is the hyperbolic rate model, which is similar to Michaelis-Menten enzyme kinetics. This model is expressed as:

$$dC/dt = -k_1 C/k_2 + C \quad (8)$$

where k_1 and k_2 are constants. The constant k_1 represents the maximum rate of degradation that is approached as the concentration increases. This model simulates a catalytic process in which degradation may be catalyzed by microorganisms.

Often an organic compound that cannot be used as a sole carbon and energy source for microorganisms is degraded. Biodegradation of the compound does not lead to energy production or cell growth. This biodegradation process is referred to as cometabolism [17] or co-oxidation if the transformation involves an oxidation reaction [18]. Cometabolism occurs when an enzyme produced by an organism to degrade one substance that supports growth also degrades another nongrowth substrate that is neither essential for, nor sufficient to, support microbial growth. The nongrowth substrate is only incompletely oxidized, or otherwise transformed, by the microorganism involved, although other microorganisms may utilize by-products of the cometabolic process. Cometabolism may be a prerequisite for the mineralization of many recalcitrant substances found in the environment, such as polycyclic aromatic hydrocarbons [19].

Measurement of physical abiotic loss mechanisms and partitioning of organic constituents in a soil should be used in conjunction with conventional degradation studies to ensure that information generated from modeling degradation represents only biological degradation of parent compounds, and not other possible disappearance mechanisms of the constituents in the soil system.

The soil is a complex system, consisting of four phases (Figure 1): (1) soil gases; (2) soil water; (3) inorganic solids; and (4) organic solids. Gases and water, which are found in the pore spaces of a soil, together comprise about 50% (by volume) of a typical soil. An organic constituent,

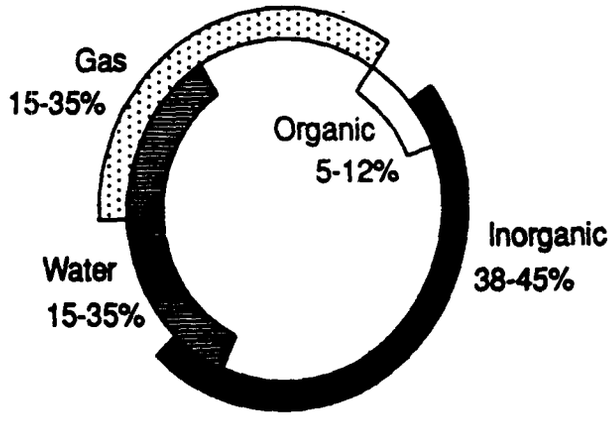


Figure 1. Typical Volumetric Composition of Soil.

depending upon its solubility and its tendency to volatilize, may be found in varying proportions in these two phases. Pore sizes and continuity and relative proportions of water and air in the pores are examples of factors that affect the mobility of contaminants (both upward out of the soil and downward to the saturated zone) in a specific soil.

Depending upon site-specific soil characteristics and constituent-specific chemical and physical properties, constituents in these two phases may be relatively mobile or immobile.

Soil solids are comprised of organic and inorganic components. The inorganic components are comprised of sparingly soluble chemicals known as minerals, which are primarily sand, silt, and clay particles in most soils. The solids may contain highly reactive charged surfaces that play an important role in immobilizing organic constituents in a specific soil. Certain types of clays are especially high in negative charges, thus exhibiting what is termed as a high cation exchange capacity. Clays may also contain positively charged surfaces and act as anion exchange media for negatively charged constituents.

Soil organic matter also has many highly reactive charged surfaces and may aid in retaining organic constituents in a soil system. The term humus refers to the relatively stable portion of soil organic matter that remains in soil after the chemicals comprising plant and animal residues have decomposed. Hydrophobic organic constituents may partition from soil water into soil organic matter and thus become less mobile in the soil system. Immobilization of constituents may result in additional time for biodegradation to occur. However, immobilization also could result in less bioavailability to microorganisms. Research is required to discover whether such immobilization constitutes adequate treatment if the constituent is so tightly and irreversibly bound that it poses no harm to human health and the environment.

Soil solid/organic chemical interactions may be quite complex. The structure of an organic constituent, as it affects such properties as molecular volume, water solubility, octanol-water partition coefficients, and vapor pressure, determines the magnitude of sorption onto the surfaces of a specific soil. The specific aspects of chemical structure that affect sorption onto soil surfaces, as summarized by Dragun [20], include:

(1) molecular size- in general, the larger the molecule, the greater its tendency to exist in the adsorbed state. This is attributed to multiple Van der Waal's forces arising from many points of contact between the soil surface and the adsorbed molecule;

(2) hydrophobicity or lipophilicity-hydrophobicity refers to the preferential migration to and accumulation of an organic chemical in hydrophobic solvents or on hydrophobic surfaces such as soil organic matter, in preference to aqueous solvents or hydrophilic surfaces. In general, molecular groups comprised of carbon, hydrogen, bromine, chlorine, and iodine are hydrophobic groups, while molecular groups containing nitrogen, sulfur, oxygen, and phosphorus are primarily hydrophilic groups. The net hydrophobicity of a molecule is determined by the combined effects of hydrophobic and hydrophilic groups that comprise the molecule;

(3) molecular charge- some organic chemicals contain functional groups with permanent positive negative or positive charges. These compounds will interact with charged soil solids and adsorb onto soil surfaces. Soils typically possess a significantly greater number of negative surfaces than positive ones, thus negatively charged organic anions may be repelled by soil surfaces. Some organic chemicals contain functional groups that may or may not possess a positive or negative charge, depending upon the acidity of the soil/water system. The pK_a of a chemical is a mathematical description of the effect of acidity on the charge of the chemical. The relative ratio of charged to uncharged molecules at a pH level in a soil/water system may be estimated and used in identification of the effect of a molecular charge on the extent of adsorption. For chemicals that possess both types of functional groups, i.e., ones that can acquire a positive charge and ones that can acquire a negative charge, the isoelectric point (IP) may be used to predict the effect of pH on the adsorption of these chemicals. The IP is the pH at which the organic chemical has zero charge. Above the IP, the organic chemical has a net negative charge; below the IP, the organic chemical has a net positive charge. The IP represents a general summation of the effects of the pK_as of each functional group in the molecule;

(4) organic molecular functional groups that undergo hydrogen bonding- hydrogen bonding occurs when a hydrogen atom serves as a bridge between two

electronegative atoms. The hydrogen atom is linked to one electronegative atom by a covalent bond and to the other by an electrostatic bond;

(5) three-dimensional arrangement and interaction of molecular functional groups- adsorption potential of a chemical is affected by intramolecular reactions of adjacent molecular groups or fragments or interference with a particular adsorption mechanism caused by the presence of one or more functional groups or molecular fragments; and

(6) molecular functional groups that undergo coordination bonding- coordination is the formation of a weak bond between an organic molecule that is capable of donating electrons and adsorbed cations that are capable of accepting electrons. The net result is a partial overlap of orbitals and a partial exchange of electron density. Coordination can occur between organic chemicals and cations in the water phase of a soil system as well as with soil particle surfaces and with adsorbed cations.

Many chemical properties of a specific organic chemical are the result of sums and interactions of functional group contributions to each specific property.

Other abiotic loss mechanisms in addition to surface sorption/desorption reactions that may account for loss of parent compounds include:

(1) hydrolysis- a chemical reaction in which an organic chemical reacts with water or a hydroxide ion;

(2) substitution and elimination- reactions where other chemicals in the soil react with an organic chemical;

(3) oxidation- the reaction resulting in the removal of electrons from a chemical. This removal generally occurs by two different pathways: (a) heterolytic or polar reactions, (an electrophilic agent attacks an organic molecule and removes an electron pair leading to the formation of an oxidized product); or (b) homolytic or free-radical reaction (an agent removes only one electron to form a radical that undergoes further reaction); and

(4) reduction- which is a reaction that results in a net gain of electrons [20].

Successful bioremediation depends upon a thorough characterization and evaluation of the pathways of movement and potential mechanisms of removal of organic constituents at a specific site, as illustrated in Figure 2. To assess the potential for use of bioremediation, the rate of transport of the constituents may be compared to the rate of degradation to determine if the rate of transport is significant in relation to the rate of degradation.

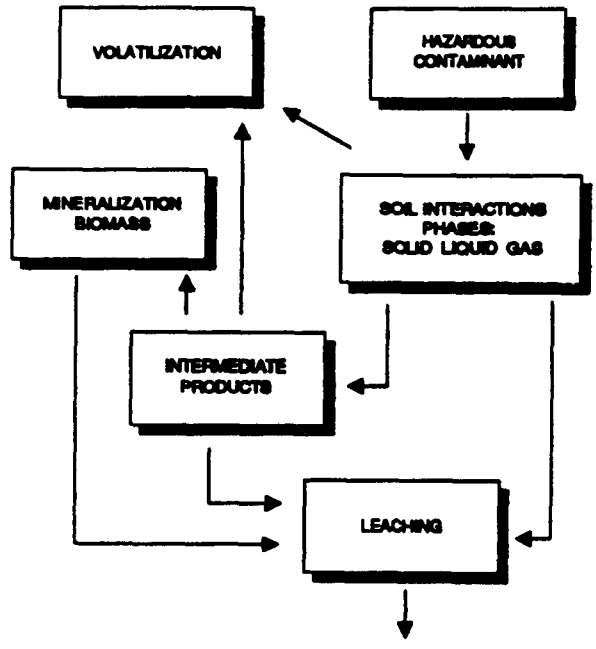


Figure 2. Fate of Hazardous Contaminants in Soil

A means of predicting rate of transport of a constituent through a soil system is to describe its mobility (or relative immobility) by predicting its retardation. Retardation is a factor that describes the relative velocity of the constituent compared to the rate of movement of water through the soil, i.e.,:

$$R = V_w/V_c \qquad (9)$$

where R = retardation factor; V_w = average water velocity; and V_c = average constituent velocity. A retardation factor greater than one indicates that a constituent is moving more slowly than water through a soil. A factor developed from a transport model combined with a description of sorption processes, as defined by a linear Freundlich isotherm [21, 22], can be calculated from the following equation:

$$R = 1 + (\rho K_d/\theta) \qquad (10)$$

where ρ = soil bulk density; K_d = soil water partition coefficient, which describes the partitioning between the soil solid phase and soil water; and θ = volumetric moisture content. This information can be used to manage a contaminated soil system (i.e., through control of soil moisture, changes in bulk density, or addition of amendments to the soil that affect the soil water partition coefficient) so that constituents can be "captured" or contained within the system, thus allowing time for implementation and performance of bioremediation treatment techniques.

3. Waste and Soil Characterization

Interfacing "soil-based behavioral characteristics" of specific organics with specific site and soil properties allows a determination of potential for bioremediation of a site and potential for contamination of other media, i.e., the ground water under the contaminated area, the atmosphere over the site or at the site boundaries, surface waters, etc. Specific characteristics important for describing and assessing the environmental behavior and fate for organic constituents in soil are listed in Table 1. For each chemical, or chemical class, the information required can be summarized as: (1) characteristics related to potential leaching, e.g., water solubility, octanol/water partition coefficient, solid sorption coefficient; (2) characteristics related to potential volatilization, e.g., vapor pressure, relative volatilization index; (3) characteristics related to potential biodegradation, e.g., half-life, degradation rate, biodegradability index; and (4) characteristics related to chemical reactivity, e.g., hydrolysis half-life, soil redox potential [21].

An adequate site characterization, including surface soil characteristics, subsurface hydrogeology, and microbiological characteristics, is the basis for the rational design of a bioremediation system. Site constraints may limit rate and/or extent of treatment of the contaminated vadose zone; therefore, a thorough site characterization is necessary to determine both the three-dimensional extent of contamination as well as engineering constraints and opportunities.

Important soil hydraulic, physical, and chemical properties that affect the behavior of organic constituents in the vadose zone are presented in Table 2. In this zone, water primarily coexists with air, though saturated regions may occur. Perched water tables may develop at interfaces of layers with differing textures. Prolonged infiltration may also result in saturated conditions. The vadose zone usually consists of topsoils, typically three to six feet deep, which are weathered geological materials, arranged in more or less well developed profiles. Water movement in the vadose zone is usually unsaturated, with soil water at less than atmospheric pressure. Weathered topsoil materials gradually merge with underlying earth materials, which may include residual or transported clays or sands. The topsoil differs from the material lying below it in that it is more weathered, contains organic matter, and is the zone of plant root growth. In some regions, the entire vadose zone may be hundreds of feet thick and the travel time constituents to ground water hundreds or thousands of years. Other regions may be underlain by shallow potable aquifers that are especially susceptible to contamination due to short transport times and reduced potential of soil materials and processes for pollutant attenuation.

Table 1. Soil-Based Waste Characterization [21]

Chemical Class	Soil Sorption Parameters	Soil Degradation Parameters	Chemical Properties
Acid	Freundlich sorption constants (K,N)	Half-life ($t_{1/2}$)	Molecular weight
Base	Sorption based on organic carbon content (K_{oc})	Rate constant (first order)	Melting point
Polar neutral	Octanol water partition coefficient (K_{ow})	Relative biodegradability	Specific gravity
Nonpolar neutral			Structure
Inorganic			Water solubility

Volatilization Parameters	Chemical Reactivity	Soil Contamination Parameters
Air:water partition coefficient (K_w)	Oxidation	Concentration in soil
Vapor pressure	Reduction	Depth of contamination
Henry's law constant ($1/K_w$)	Hydrolysis	Date of contamination
Sorption based on organic carbon content (K_{oc})	Precipitation	
Water solubility	Polymerization	

Table 2. Site and Soil Characteristics Identified as Important in In Situ Treatment [21]

Site location/topography and slope
Soil type, and extent
Soil profile properties
boundary characteristics
depth
texture*
amount and type of coarse fragments
structure*
color
degree of mottling
bulk density*
clay content
type of clay
cation exchange capacity*
organic matter content*
pH*
Eh*
aeration status*
Hydraulic properties and conditions
soil water characteristic curve
field capacity/permanent wilting point
water holding capacity*
permeability* (under saturated and a range of unsaturated conditions)
infiltration rates*
depth to impermeable layer or bedrock
depth to groundwater,* including seasonal variations
flooding frequency
runoff potential*
Geological and hydrogeological factors
subsurface geological features
groundwater flow patterns and characteristics
Meteorological and climatological data
wind velocity and direction
temperature
precipitation
water budget

*Factors that may be managed to enhance soil treatment

Microbiological characterization of a contaminated site should be conducted to ensure that the site has a viable community of microorganisms to accomplish biodegradation of the organic constituents present at the site. Approaches for estimating the kinds, numbers, and metabolic activities of soil organisms include:

(1) determination of the form, arrangement, and biomass of microorganisms in the soil;

(2) isolation and characterization of subgroups and species; and

(3) detection and measurement of metabolic processes [15].

Examples of techniques to accomplish these activities include direct microscopy of soil (e.g., fluorescent staining, buried-slide technique), biomass measurement by chemical techniques (e.g., measurement of ATP), measurement of enzyme activity, and cultural counts of microorganisms (e.g., plate counts, dilution counts, isolation of specific organisms). Biotransformation studies that measure the disappearance of contaminants or mineralization studies that indicate complete destruction of contaminants to carbon dioxide and water may be used to confirm the potential for biodegradation of specific organic chemicals. Specific techniques include batch culture and electrolytic respirometer studies. Controls to detect abiotic transformation of the contaminants and tests to detect toxic effects of contaminants on microbial activity should be included in the studies.

Information from waste and soil/site characterization studies of a specific site and from laboratory evaluations of biodegradation and immobilization potential of specific constituents at the site may be integrated by the use of predictive mathematical models. The resulting mathematical description may be used to: (1) evaluate the effectiveness of use of on-site bioremediation for treatment of the contaminated soil; (2) develop appropriate containment structures to prevent unacceptable waste transport from the treatment zone; and (3) design performance monitoring strategies.

4. Microbial Factors Affecting Biodegradation

The upper layers of soil contain large numbers and diversity of microorganisms. Biodegradation of organic constituents is accomplished by enzymes produced by the microorganisms. Since many enzymes are not released by microbial cells, substances to be degraded must contact or be transported into the cells. Enzymes are generally specific in the substances they affect, so many types may be required to complete biodegradation of organic constituents. The production of enzymes is genetically controlled, thus mutations and adaptations of the native soil microbial populations can improve the ability of the populations to degrade organic substances [23].

Microbial ecologists have identified ranges of critical environmental conditions that affect the activity of soil microorganisms (Table 3). Many of these conditions are controllable and can be changed to enhance biodegradation of organic constituents.

Water is necessary for microbial life, and the soil water matric potential against which microorganisms must extract water from the soil regulates their activity. (The soil matric

Table 3. Critical Environmental Factors for Microbial Activity [15, 21, 23]

Environmental Factor	Optimum Levels
Available soil water	25 - 85% of water holding capacity; -0.01 MPa
Oxygen	Aerobic metabolism: Greater than 0.2 mg/l dissolved oxygen, minimum air-filled pore space of 10%; Anaerobic metabolism: O_2 concentrations less than 1%
Redox potential	Aerobes and facultative anaerobes: greater than 50 millivolts; Anaerobes: less than 50 millivolts
pH	5.5 - 8.5
Nutrients	Sufficient nitrogen, phosphorus, and other nutrients so not limiting to microbial growth (Suggested C:N:P ratio of 120:10:1)
Temperature	15 - 45° C (Mesophiles)

potential is the energy required to extract water from the soil pores to overcome capillary and adsorptive forces). Soil water also serves as the transport medium through which many nutrients and organic constituents diffuse to the microbial cell, and through which metabolic waste products are removed. Soil water also affects soil aeration status, nature and amount of soluble materials, soil water osmotic pressure, and the pH of the soil solution [15].

Microbial respiration, plant root respiration, and respiration of other organisms remove oxygen from the soil atmosphere and enrich it with carbon dioxide. Gases diffuse into the soil from the air above it, and gases in the soil atmosphere diffuse into the air. However, oxygen concentration in a soil may be much less than in air while carbon dioxide concentrations may be many times that of air. Even so, a large fraction of the microbial population within the soil depends on oxygen as the terminal electron acceptor in metabolism. When soil pores become filled with water, the diffusion of gases through the soil is restricted. Oxygen may be consumed faster than it can be replaced by diffusion from the atmosphere, and the soil may become anaerobic. Clay content of soil and the presence of organic matter also may affect oxygen content in soil. Clayey soils tend to retain a higher moisture content, which restricts oxygen diffusion, while organic matter may increase microbial activity and deplete available oxygen. Loss of oxygen as a metabolic electron acceptor induces a change in the activity and composition of the soil microbial population. Facultative anaerobic organisms, which can use oxygen when it is present or can switch to alternative electron acceptors such as nitrate or sulfate in the absence of oxygen, and obligate anaerobic organisms become the dominant populations.

Another soil parameter that describes the effect of the soil environment on metabolic processes is the redox potential of the soil [15]. Biological energy is obtained from the oxidation of reduced materials. Electrons are removed from organic or inorganic substrates to capture the energy that is available during the oxidative process. Electrons from reduced compounds are moved along respiratory or electron transport chains composed of a series of compounds. In an aerobic process, O_2 acts as the terminal electron acceptor. In some cases where O_2 is not available, nitrate (NO_3^-), iron (Fe^{3+}), manganese (Mn^{2+}), and sulfate (SO_4^{2-}) can act as electron acceptors if the organisms have the appropriate enzyme systems. A measurement of the oxidation-reduction potential (redox potential) of a soil provides a measurement of the electron density of the system. As a system becomes reduced, O_2 is depleted, and other substances are used as terminal electron acceptors. There is a corresponding increase in electron density, resulting in a progressively increased negative potential. Redox potential is measured as E_h, expressed in millivolts, or as P_E, which is equal to -log $[e^-]$ where $[e^-]$ is the concentration of negatively charged electrons.

Oxygen levels in a soil system can be maintained by:

(1) prevention of saturation with water;

(2) presence of sandy and loamy soil materials (excessive clay contents are undesirable);

(3) moderate tilling;

(4) avoidance of compaction of soil; and

(5) limited addition of additional carbonaceous materials [23].

Soil pH also affects the activity of soil microorganisms. Fungi are generally more tolerant of acidic soil conditions (below pH 5) than are bacteria. The solubility of phosphorus, an important nutrient in biological systems, is maximized at a pH value of 6.5. A specific contaminated soil system may require management of soil pH to achieve levels that maximize microbial activity. Control of pH to enhance microbial activity may also aid in the immobilization of hazardous metals in a soil system (a pH level greater than 6 is recommended to minimize metal transport).

Microbial metabolism and growth is dependent upon adequate supplies of essential macro- and micronutrients. Required nutrients must be present and available to

microorganisms in: (1) a usable form; (2) appropriate concentrations; and (3) proper ratios [20]. If the wastes present at the site are high in carbonaceous materials and low in nitrogen (N) and phosphorus (P), the soils may become depleted of available N and P required for biodegradation of the organic constituents. Fertilization may be required at some contaminated sites as a management technique to enhance microbial degradation. Biodegradation of organic constituents declines with lowering of soil temperature due to reduced microbial growth and metabolic activity. Biodegradation has been shown to essentially stop at a temperature of 0° C. Soils exhibit a variation in the temperature of the surface layers, both diurnally and seasonally. Diurnal changes of temperature decrease with depth of the soil profile. Due to the high specific heat of water, wet soils are less subject to large diurnal changes than dry soils [15]. Factors that affect soil temperature include soil aspect (direction of slope), steepness of slope, degree of shading, soil color, and surface cover.

The environmental factors presented in Table 3, as well as soil and waste characteristics, interact to affect microbial activity at a specific contaminated site. Computer modeling techniques are useful to attempt to describe the interactions and their effects on treatment of organic constituents in a specific situation.

5. Treatability Studies for Determination of Bioremediation Potential

Treatability studies for sites contaminated with organic wastes are used to provide specific information concerning the potential rate and extent of bioremediation of surficial soil and deeper vadose zone soils by providing information on fate and behavior of organic constituents at a specific contaminated site. Treatability studies can be conducted in laboratory microcosms, at pilot scale facilities, or in the field. To determine whether a specific site is suitable for bioremediation, information from treatability studies is combined with information concerning site and waste characteristics in order to determine potential applications and limitations of the technology. Ultimate limitations to the use of bioremediation at a specific site are usually related to: (1) time required for cleanup, (2) level of cleanup attainable, and (3) cost of cleanup using bioremediation.

Information from treatability studies also is used to prepare an approach to the engineering design and implementation of a bioremediation system at a specific site. An engineering design to accomplish bioremediation at the site is generally based upon information from simulations (e.g., mathematical modeling) or estimates of pathways of migration of chemicals. These simulations or estimates are generated from treatability data and site/soil characterization data in order to: (1) determine containment requirements to prevent contamination of off-site receiver systems; (2) develop techniques to maximize mass transfer of chemicals affecting microorganism activity (addition of mineral nutrients, oxygen, additional energy sources, pH control products, etc.; removal of toxic products) in order to enhance bioremediation; and (3) design a cost-effective and efficient monitoring program to evaluate effectiveness of treatment.

Table 4. Materials Balances and Mineralization Approaches to Biodegradation Assessment

Biodegradation Approach	Process Examined
Materials balances	Recovery of parent compound in the air, soil water, soil solids (extractable)
	Recovery of transformation products in the air, soil water, and soil solids (extractable)
Mineralization	Production of carbon dioxide, and/ or methane from the parent compound
	Release of substituent groups, e.g., chloride or bromide ions

During the performance of a treatability study, biodegradation, detoxification, and partitioning (immobilization) processes are evaluated as they affect the fate and behavior of organic constituents in the soil.

To assess the potential for biological degradation at a specific contaminated site, the use of treatability studies incorporating materials balance and mineralization approaches to determine the environmental fate and behavior of the constituents in the specific soil is recommended (Table 4). Rate of degradation is calculated by measuring the loss of parent compound and the production of carbon dioxide with time of treatment. Degradation rate is often reported as half-life, which represents the time required for 50 percent of the compound to disappear based upon a first-order kinetic model.

Calculation of the rate of decrease of parent compound, however, by itself does not provide complete information concerning mechanisms and pathways by which organic constituents are interacting with the soil environment [24]. Further information is necessary to understand whether a constituent is simply transferred from one phase (e.g., solid phase) to another (e.g., air phase) through a process of interphase transfer, or is chemically altered so that the

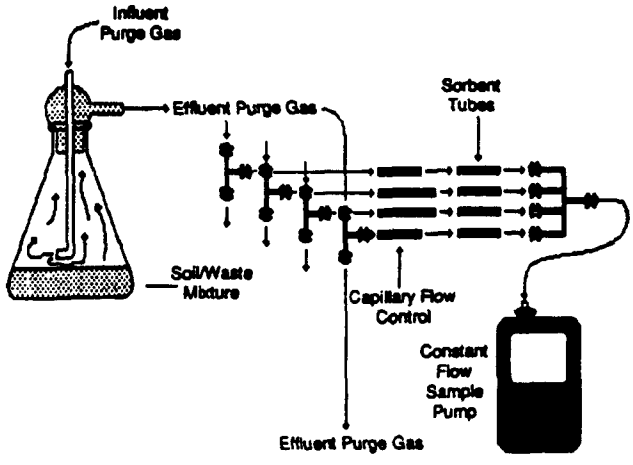


Figure 3. Laboratory Flask Apparatus Used for Mass Balance Measurements.

properties of the parent compound are destroyed. Evaluation of the fate of a constituent in a soil therefore also requires identification and measurement of the distribution of the constituent among the physical phases that comprise the system as well as differentiation of the mechanisms by which constituent may be chemically altered in a soil system.

A laboratory flask apparatus that can be used as a microcosm to measure interphase transfer and biodegradation potential in a laboratory treatability study is illustrated in Figure 3. The contaminated soil material is placed in a flask, which is then closed and incubated under controlled conditions for a period of time. During the incubation period, air is drawn through the flask and then through a sorbent material. Volatilized materials are collected by the sorbent and are measured to provide an estimate of volatilization loss of the constituents of interest. At the end of the incubation period, a portion of the contaminated soil is treated with an extracting solution to determine the extent of loss of the constituents in the soil matrix. This loss can be attributed to biodegradation and possible immobilization in the soil materials. Selection of an appropriate extracting solution is necessary to maximize constituent recovery from the soil. Another portion of the soil is leached with water to determine leaching potential of remaining constituents. Abiotic processes involved in removal of the parent compound are also evaluated by comparing microbially active soil/waste mixtures with mixtures that have been treated with a microbial poison, e.g., mercuric chloride or propylene oxide. The use of a procedure incorporating features illustrated by the use of this microcosm is crucial in order to obtain a materials balance of waste constituents in the soil system. Examples of such protocols may be found in [14, 24, 25, 26]. A certain amount of material is added to the soil, and tracking the fate of the material as it moves through the multiple phases of the soil system provides a materials balance.

Transformation refers to the partial alteration of hazardous constituents into intermediate products. Intermediate products may be less toxic or more toxic than the parent compound, and therefore the rate and extent of detoxification of the contaminated material should be evaluated. Samples generated from the different phases of the soil system in the microcosm studies can be analyzed for intermediate degradation products and used in bioassay studies to provide information concerning transformation and detoxification processes.

Bioassays to quantify toxicity measure the effect of a chemical on a test species under specified test conditions [14]. The toxicity of a chemical is proportional to the severity of the chemical on the monitored response of the test organism(s). Toxicity assays utilize test species that include rats, fish, invertebrates, microorganisms, and seeds. The assays may utilize single or multiple species of test organisms. The use of a single bioassay procedure does not provide a comprehensive evaluation of the toxicity of a chemical in the soil/organic chemical-impacted system. Often a battery of bioassays is utilized that may include measurements of effects on general microbial activity (e.g., respiration, dehydrogenase activity) as well as assays relating to activity of subgroups of the microbial community (e.g., nitrification, nitrogen fixation, cellulose decomposition). Bioassays utilizing organisms from different ecological trophic levels may also be used to determine toxicological effects. However, use of a single assay as a screening test to identify relative toxicity reduction in the environment is a common procedure employed in treatability studies. Assays using microorganisms are often used due to their speed, simplicity, ease in handling, cost effectiveness, and use of a statistically significant number of test organisms that is required to detect the effects of potentially toxic materials in the environment [27, 28].

Two microbial bioassays that have been used to evaluate toxicity of wastes in soil systems are the Ames *Salmonella typhimurium* mammalian microsome assay and the Microtox™ test system. The Ames assay is a measure of the mutagenic potential of hazardous compounds [29, 30] and has been widely used to evaluate environmental samples [31, 32, 33, 34, 35]. A high correlation has been shown between carcinogenicity and mutagenicity, where about 90% of known carcinogens tested mutagenic in the Ames assay [36]. Special strains of *Salmonella typhimurium* that require histidine to grow are used to test for mutagenicity. When plated on a histidine-free medium, the only bacteria able to form colonies are those that have reverted to the "wild" state and are able to produce their own histidine. Without the addition of test chemicals, this back mutation occurs at a rate specific to each strain type (spontaneous reversion rate). The addition of chemicals that are mutagenic increases the reversion rate. Several dose levels of a chemical, mixture of chemicals, or an environmental sample are added to obtain a dose response. Some mutagens act directly on the bacterial cells while others require activation by mammalian

microsomes. These microsomes are generally obtained from liver extracts of Aroclor 1254-induced rats (i.e., rats injected with the polychlorinated biphenyl (PCB), Aroclor 1254). The extract, referred to as the S-9 fraction, contains enzymes that metabolically convert certain chemicals to active mutagens, simulating the activity that occurs in living mammalian systems. Several strains of *Salmonella typhimurium* have been developed in order to detect different types of mutagens. The recommended strains for general mutagenicity testing include TA97, TA98, TA100, TA102. TA97 and TA98 detect frameshift mutagens. TA100 detects mutagens causing base-pair substitutions, while TA102 detects a variety of mutagens not detected by the other strains.

The Microtox™ assay is an aqueous general toxicity assay that measures the reduction in light output produced by a suspension of marine luminescent bacteria in response to an environmental sample [37]. Bioluminescence of the test organism depends on a complex chain of biochemical reactions. Chemical inhibition of any of the biochemical reactions causes a reduction in bacterial luminescence. Therefore, the Microtox™ test considers the physiological effect of a toxicant and not just mortality. Matthews and Bulich [38] have described a method of using the Microtox™ assay to predict the land treatability of hazardous organic wastes. Matthews and Hastings [39] described a method using the Microtox™ assay to determine an appropriate range of waste application loading for soil-based treatment systems. Symons and Sims [40] utilized the assay to assess the detoxification of a complex petroleum waste in a soil environment. The assay was also included as a recommended bioassay in the U.S. EPA Permit Guidance Manual on Hazardous Waste Land Treatment Demonstrations [25].

Immobilization refers to extent of retardation of the downward transport (leaching potential) and upward transport (volatilization potential) of waste constituents. Interphase transfer potential for waste constituents among soil, oil (waste), water, air, and solid (organic and inorganic) phases is affected by the relative affinity of the waste constituents for each phase, and may be quantified through calculation of partition coefficients [25]. Partition coefficients are calculated as the ratio of the concentration of a chemical in the soil, oil, or air phase to the concentration of a chemical in the water phase, and are expressed as Ko (oil/water), Kh (air/water), and Kd (solid/water). Calculation of retardation factors (Equations 9 and 10) also may be used to predict immobilization of constituents in a soil system [22, 41].

Either laboratory microcosm, pilot scale reactors, or field plots may be used to generate treatability data. The set of experimental conditions, e.g., temperature, moisture, waste concentration, etc., under which the studies were conducted should be presented along with experimental results.

Treatability study results provide information relating to rates and extent of treatment of hazardous organic constituents when mass transfer rates of potential limiting substances are not limiting the treatment. Treatability studies usually represent optimum conditions with respect to mixing, contact of soil solid materials with waste constituents and with microorganisms, and homogeneous conditions throughout the microcosm. Therefore, treatability studies provide information concerning potential levels of treatment achievable at a specific site. Under field conditions, the rate and extent of bioremediation is generally limited by accessibility and rate of mass transfer of chemical substances (oxygen, nutrients, etc.) to the contaminated soil as well as by mass transfer of the contaminants to the microbial population and removal of microbial degradation products.

6. Integration of Information from Site Characterization and Treatability Studies

Information from the performance of site characterization and treatability studies may be integrated with the use of comprehensive mathematical modeling. In general, models are used to analyze the behavior of an environmental system under both current (or past) conditions and anticipated (or future) conditions [42]. A mathematical model provides a tool for integrating degradation and partitioning processes with site/soil- and waste-specific characterization for simulating the behavior of organic constituents in a contaminated soil and for predicting the pathways of migration through the contaminated area, and therefore pathways of exposure to humans and to the environment. Models may also be used to approximate and estimate the rates and extent of treatment that may be expected at the field scale under varying conditions. DiGiulio and Suffet [43] have presented guidance on the selection of appropriate vadose zone models for site-specific applications, focusing on recognition of limitations of process descriptions of models and difficulties in obtaining input parameters required by these process descriptions.

The Regulatory and Investigative Treatment Zone Model (RITZ Model, developed at the U.S. EPA Robert S. Kerr Environmental Research Laboratory by Short [44]) is an example of a model that has been used to describe the potential fate and behavior of organic constituents in a contaminated soil system [45]. The Ritz Model is based on an approach by Jury [46]. An expanded version of RITZ, the Vadose Zone Interactive Processes (VIP) model, incorporates predictive capabilities for the dynamic behavior of organic constituents in unsaturated soil systems under conditions of variable precipitation, temperature, and waste loadings [25, 47, 48, 49, 50]. Both models simulate vadose zone processes, including volatilization, degradation, sorption/desorption, advection, and dispersion [51].

Once interphase transfer potential and pathways of escape have been identified by treatability studies and simulation modeling, containment requirements for the constituents of interest at the site can be determined. If the major pathway of transport is volatilization, containment with respect to volatilization control is required. An inflatable plastic dome erected over a contaminated site is a containment method that has been used to control escape of volatile constituents. Volatiles are drawn from the dome through a conduit and treated in an above ground treatment system. If leaching has been identified as important, control of soil water movement should be implemented. For example, if contaminated materials are expected to leach downward from the site, the contaminated materials can be temporarily removed from the site, and a plastic or clay liner placed under the site. When downward, as well as upward, migration is significant, both volatilization and leaching containment systems can be installed. Some hydrophobic chemicals do not tend to volatilize or to leach but are persistent within the soil solid phase; therefore, containment efforts may not be required.

A critical and cost-effective use of modeling is in the analysis of proposed or alternative future conditions, i.e., the model is used as a management or decision-making tool to help answer "what if" type questions [42]. Attempting to answer such questions through data collection programs would be expensive and practically impossible in many situations. For example, information can be generated to evaluate the effects of using different approaches for enhancing microbial activity and for accelerating biodegradation and detoxification of the contaminated area by altering environmental conditions that affect microbial activity.

Results of modeling also can aid in the identification of constituents that will require treatment in the air (volatile) phase, in the leachate phase, and in the solid (soil) phase. Monitoring efforts therefore can be concentrated on monitoring the appropriate environmental phase to evaluate treatment effectiveness. If a comprehensive and thorough evaluation of a specific contaminated system has been conducted, not all chemicals need to be monitored in each phase.

7. Potential Applications and Limitations of Bioremediation Technology

Existing information for constituents of interest at a specific site/soil contaminated system should be collected as a first step in the investigation of the application of bioremediation as a potential treatment technology. Many organic constituents from a wide range of chemical classes have been shown to be amenable to biodegradation in laboratory studies, using both single strains of microbial species or consortia of microbial populations. Biodegradation has also been demonstrated in both aqueous cultures or soil microcosm studies. A summary of biodegradation and disappearance rates for almost 300 chemicals has been prepared by Dragun [20]. Examples of specific chemical classes shown to be biodegradable include: amines and alcohols [14]; polycyclic aromatic hydrocarbons (PAHs) [5, 12, 13, 52, 53]; chlorinated and non-chlorinated phenols [14]; chlorinated aromatic hydrocarbons [54]; polychlorinated biphenyls (PCBs) [55], halogenated aliphatic compounds [50, 57]; pesticides [13, 47, 58, 59, 60, 61]; and various hazardous substances [13, 62]. Industrial wastes from petroleum refining, wood preserving, leather tanning, coal gasification/liquefaction, food processing, pulp and paper manufacturing, organic chemical production, animal production, munitions production, textile manufacturing, pesticide manufacturing, and pharmaceutical manufacturing, as well as municipal wastewaters, sludges, and septage from septic tanks, have all been successfully treated in land treatment systems [14, 20].

RSKERL, as part of its responsibilities to manage research programs to determine the fate, transport, and transformation rates of pollutants in the soil, the unsaturated and the saturated zones of the subsurface environment, initiated a research program to develop comprehensive screening data on the treatability in soil of specific listed hazardous organic chemicals and specific listed hazardous wastes. Research results have been presented by Sims et al. [13], Loehr [14], and McGinnis et al. [5]. A Soil Transport and Fate (STF) Data Base was also developed for RSKERL [63]. The Data Base contains quantitative and qualitative information on degradation, transformation, partitioning among the soil phases, and toxicity of hazardous organic constituents in soil systems. It may be used as a tool for contaminated site assessment and remediation activities. The Data Base provides input data concerning degradation rates, partition coefficients, and chemical property data for mathematical models simulating the behavior and fate of chemical constituents in contaminated surface and subsurface soils. The information is also useful for providing assistance in determining treatment potential at contaminated sites using in situ techniques. Chemicals may be evaluated with respect to the importance of natural processes in controlling persistence and transport potential, and therefore, the susceptibility to degradation or retardation within a subsurface environment.

A report was prepared for the U.S. EPA evaluating the effectiveness of soil treatment practices at Superfund sites, EPA Office of Research and Development tests, Department of Defense and Department of Energy studies, state remediation efforts, private party studies, and vendor demonstrations [64, 65]. Bioremediation was shown to successfully treat many non-halogenated compounds, but was less successful with halogenated compounds. Removal efficiencies for non-halogenated aromatics, heterocyclics and other polar compounds were greater than 95%. Halogenated aliphatic compounds were also

successfully treated, with removal efficiencies averaging 98%; however, volatilization may have contributed to observed losses. More complex halogenated and nitrated compounds exhibited lower removal efficiencies, ranging from 50 to 85%.

Even though a specific organic constituent has been shown to biodegrade under laboratory conditions, whether or not it will degrade in a specific soil/site system is dependent on many factors [54]. Potential degradability requires investigation in site-specific treatability studies. Available oxygen may be limiting in some cases, while other compounds may require the presence of anaerobic conditions. Other environmental conditions that may place restrictions on biological activity include pH, temperature, and moisture. Upon exposure to the soil environment, the constituent may be biologically or chemically altered so as to be rendered persistent and/or toxic in the environment.

The system may lack other nutrients required for microbial activity. Other chemicals present may serve as preferred substrates, or act to repress required enzyme activities. High concentrations of metal salts may be inhibitory or toxic to many microorganisms.

Most chemicals require the presence of a consortium of microbial species for mineralization, some of which may not be present at the specific site. Also, most organisms require a period of acclimation to the constituent before metabolism occurs. During this period, the level of constituent must be high enough to promote acclimation without being toxic or inhibitory. Prior exposure to the constituent or similar constituents may help to shorten the acclimation period.

8. Example of Bioremediation Potential for Polycyclic Aromatic Hydrocarbons (PAHs) in a Soil System

To demonstrate the potential effectiveness of bioremediation, results are presented for the semi-volatile chemical class of compounds known as the polycyclic aromatic hydrocarbons (PAHs). These compounds are of environmental significance because of their recalcitrance to biological degradation, their chronic toxic effects on humans, and their widespread occurrence at contaminated waste sites. Specifically, PAH compounds are associated with oily wastes, such as wastes from petroleum refining operations and wastes from the wood preserving industry. The higher molecular weight PAH compounds are of special concern, because they exhibit mutagenic, carcinogenic, and teratogenic potential.

Table 5. Degradation of PAHs Present in a Complex Oily Waste, Applied at 2% Oil and Grease in Clay Loam Soil [66]

Compound	C_0* µg/g	$t_{1/2}$* days	R^2	95% Confidence Interval ($t_{1/2}$) (days)	
				Lower	Upper
Fluoranthene	351	15	0.966	13	18
Pyrene	283	32	0.884	26	41
Benzo(a) anthracene	86	139	0.397	87	347
Benzo(g,h,i)perylene	8	1661	0.006	139	ND
Indeno-pyrene	5	69	0.559	43	139

* C_0 = Initial Concentration

* $t_{1/2}$ = Half-life (first order kinetics)

Table 6. Effect of Manure and pH Amendments on PAH Degradation in a Complex Waste Incorporated into Soil [67]

PAH Compound	Half-Life in Waste/Soil Mixture (days) Without Amendments	With Amendments
Acenaphthylene	78	14
Acenaphthene	96	45
Fluorene	64	39
Phenanthrene	69	23
Anthracene	28	17
Fluoranthene	104	29
Pyrene	73	27
Benz(a)anthracene	123	52
Chrysene	70	42
Benzo(b)fluoranthene	85	65
Benzo(k)fluoranthene	143	74
Benzo(a)pyrene	91	69
benzo(ghi)perylene	74	42
Dibenz(a,h)anthracene	179	70
Indeno(1,2,3-cd)pyrene	57	42

Table 7. Effect of Soil Moisture on PAH Degradation [67]

Moisture	Half-life in Waste/Soil Mixture (Days) Anthracene	Phenanthrene	Fluoranthene
20-40% field capacity	43	61	559
60-60% field capacity	37	54	231

The degradation of PAH compounds in soils has been demonstrated in laboratory treatability studies [66]. The results presented in Table 5 for PAH compounds present in a complex oily waste show that the half-lives for four of the five compounds ranged from only 15 to 139 days. However, the half-life for benzo(g,h,i)perylene, a higher molecular weight PAH compound, was still quite long (1661 days). McGinnis et al. [5] in a laboratory soil treatability study of PAH compounds present in creosote waste sludges also found that degradation of PAH was dependent on molecular weight and number of aromatic rings. PAHs with two rings generally exhibited half-lives less than ten days, while three- ring compounds in most cases exhibited longer half-lives, which were usually less than one hundred days. Most of the four- or five-ring PAHs exhibited half lives of one hundred days or more. The results of these two studies suggest that means of enhancing biological degradation of more recalcitrant PAH compounds should be investigated.

When additional carbon and energy sources were provided and soil pH was adjusted from 6.1 to 7.5, the half-lives of PAH waste constituents present in a complex fossil fuel waste added to a soil were decreased, as shown in Table 6 [67]. In this laboratory study using first-order kinetic modeling of degradation, the use of manure as an amendment and control of soil pH significantly decreased the $t_{1/2}$ of the PAH constituents studied. For example, the half-life of phenanthrene decreased from 69 to 23 days, benz(a)anthracene from 123 to 52 days, and benz(a)pyrene from 91 to 69 days.

The control of soil moisture also resulted in enhanced biodegradation of PAHs, as shown in Table 7 [67]. Soil moisture in this study was described in terms of percent of field capacity. Field capacity is defined as the percentage of soil moisture remaining in a soil after having been saturated and after free drainage has practically ceased. Therefore, soils with moisture levels of 60 to 80% of field capacity are wetter than soils with levels of 20 to 40% of field capacity. At higher levels of soil moisture, the half-life of the PAH constituents studied decreased. For example, for fluoranthene, the half-life decreased from 559 days to 231 days. At a specific site where containment has been achieved, the addition and control of soil moisture may be a tool to accomplish faster degradation of the constituents.

An increase in soil temperature also can decrease the time required to accomplish degradation, especially the loss of lower molecular weight PAHs [68]. In a laboratory study, for example, the half-life of fluorene decreased from 60 days to 47 days to 32 days at 10°, 20°, and 30° C, respectively (Table 8). At a field site, soil temperature may be difficult to control. However, if a cover is used at the site to control the release of volatile materials, an increase in soil temperature may also occur. Seasonal climatic changes will affect the rate of degradation of organic constituents, as well as geographical location of a specific contaminated site.

If a soil has been exposed previously to similar or the same type of contamination, the soil microbial population may have become acclimated to the waste, and waste degradation may occur at a faster rate. In a laboratory study investigating the acclimation of a soil to a fossil fuel waste, a greater reduction in concentration of all the waste PAH compounds studied was achieved in 22 days in an acclimated soil, compared to the reduction seen in 40 days in an unacclimated soil (Table 9) [67]. These results show that at a site that has been contaminated for a period of time, the indigenous microbial population may become acclimated to the presence of wastes, and techniques to stimulate microbial activity may produce significant degradation. Mixing of a small amount of a contaminated soil that has developed an acclimated population with the

Table 8. Percentages of PAH Remaining at the End of the 240 Day Study Period and Estimated Apparent Loss Half Lives [68]

Compound	Percent of PAH Remaining 10°C	20°C	30°C	Estimated Half Life (day)* 10°C	20°C	30°C
Acenaphthene	5	0	0	<60	<10	<10
Fluorene	8	3	2	60(+11/-10)	47(+6/-5)	32(+5/-3)
Phenanthrene	36	19	2	200(+40/-40)	<60	<60
Anthracene	83	51	58	460(+310/-140)	260(+160/-70)	200(+90/-30)
Fluoranthene	94	71	15	+	440(+560/-160)	140(+40/-20)
Pyrene	93	89	43	+	1900(+6200/-800)	210(+160/-60)
Benz(a)anthracene	82	71	50	680(+300/-160)	430(+110/-70)	240(+40/-40)
Chrysene	85	88	86	980(+520/-270)	1000(+900/-250)	730(+370/-180)
Benzo(b)fluoranthene	77	75	62	580(+520/-180)	610(+590/-200)	360(+150/-80)
Benzo(k)fluoranthene	93	95	89	910(+690/-270)	1400(+3300/-560)	910(+4400/-410)
Benzo(a)pyrene	73	54	53	530(+1700/-230)	290(+570/-120)	220(+160/-60)
Dibenz(a,h)anthracene	88	87	83	820(+1100/-300)	750(+850/-260)	940(+12000/-450)
Benzo(g,h,i)perylene	81	76	75	650(+650/-230)	600(+570/-190)	590(+1800/-250)
Indeno(1,2,3-c,d)pyrene	80	77	70	600(+310/-150)	730(+1100/-270)	630(+2500/-280)

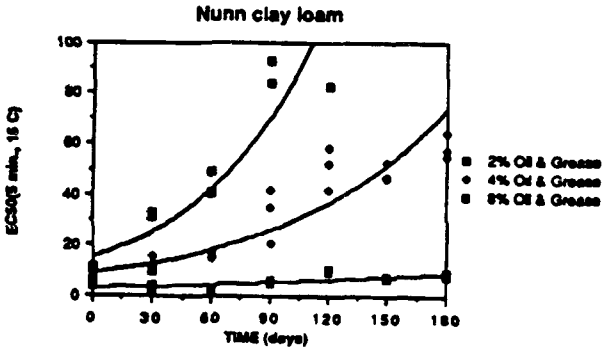
* $t_{1/2}$ (95 percent confidence interval)
\+ Least squares slope (for calculation of $t_{1/2}$) = zero with 95% confidence.

Table 9. Acclimation of Soil to Complex Fossil Fuel Waste [67]

PAH Compound	Unacclimated Soil: Initial Soil Concentration (mg/kg-dry wt)	Unacclimated Soil: Reduction in 40 days (%)	Acclimated Soil: Soil Concentration after First Reapplication of Waste (after 168 days incubation at initial level) (mg/kg-dry wt)	Acclimated Soil: Reduction in 22 days (%)
Naphthalene	38	90	38	100
Phenanthrene	30	70	30	83
Anthracene	38	58	38	99
Fluoranthene	154	51	159	82
Pyrene	177	47	180	86
Benz(a)anthracene	30	42	40	70
Chrysene	27	25	33	61
Benz(a)pyrene)	10	40	12	50

contaminated soil to be treated may also result in faster cleanup of a site. Amendment of the soil with exogenous microorganisms developed in laboratory batch cultures would not be required.

One method to assess detoxification of waste constituents in a soil system involves use of the Microtox™ assay [38]. The assay is used to measure acute toxicity of aqueous solutions or water soluble fraction extracts. The Microtox™ system is a standardized instrumental-based system that utilizes a suspension of marine luminescent bacteria (*Photobacterium phosphoreum*) as bioassay organisms. The bioassay organisms are handled like chemical reagents. Suspensions of about one million bacteria are "challenged" with additions of serial dilutions of an aqueous sample or extract. Light output from each bacterial suspension is measured before and after each addition of sample. Results are presented as EC50 values, which are defined as sample concentrations resulting in a 50% decrease of light produced by the luminescent bacteria. High EC50 values indicate lower toxicity than low values. Detoxification of a contaminated soil system is indicated by increased Microtox™ EC50 values approaching 100%. A value of 100% is considered as non-toxic.



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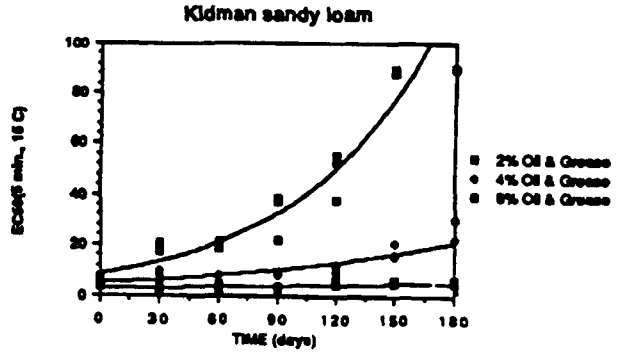

4b

Figure 4. EC50 as a Function of Time for Two Soils and Three Waste Loading Rates

In a clay loam soil, a petroleum refinery waste was added to soil at application rates of 2%, 4%, and 8% by weight of oil and grease [40]. The results of the study are shown in Figure 4. Time of incubation is plotted on the x-axis, and EC50 values, as determined by the Microtox™ assay,on the y-axis. At the 2% loading rate, the waste material was detoxified to an EC50 value of 100 in a period of about 100 days (Figure 4a). At the highest level of contamination (8% loading rate), the materials remained toxic, even after 180 days. In addition to providing evidence of detoxification of waste constituents, this study also showed the potential for enhancement of biodegradation by mixing uncontaminated soil with contaminated soil to produce a treatment medium with waste contents at levels not toxic to microbial populations.

In a sandy loam soil amended with the same contaminated material, a longer period (about 170 days) was required to detoxify the 2% contamination level to an EC50 value of 100% (Figure 4b). Results of these studies show that mixing of contaminated soils with uncontaminated soils can result in detoxification. However, since the rate of detoxification may be a function of soil type, these results also illustrate the site specificity of bioremediation efforts and underscore the need to perform site-specific characterization of the contaminated area.

Another technique to assess detoxification of organic constituents in a soil system is the use of the Ames *Salmonella typhimurium* assay [29, 30, 52]. The assay utilizes the bacterium *S. typhimurium* to indicate the presence of mutagenic constituents, which may include

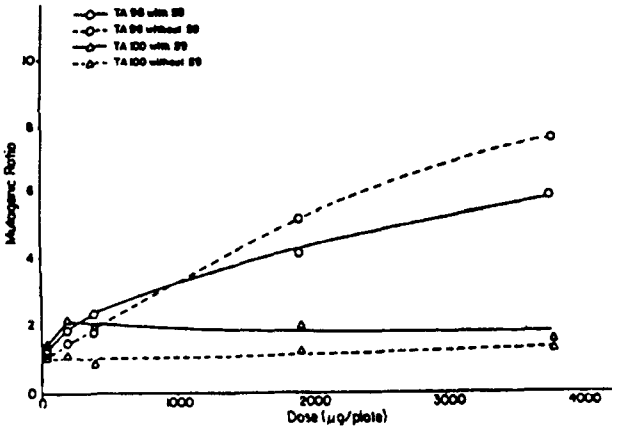

Figure 5. Ames Assay Results for Waste; Soil Mixture Immediately After Waste Incorporation into Soil [67]

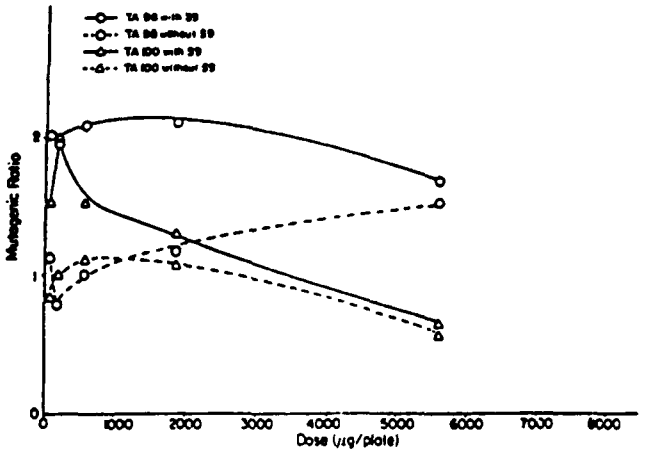

Figure 6. Ames Assay Results for Waste; Soil Mixture After Forty-two Days Incubation [67]

transformation products of parent compounds. Different strains of *S. typhimurium* are selected to indicate the mechanism of mutagenicity, i.e., point mutations or frame-shift mutations. Mutagenicity is measured as a ratio of the number of colonies that grow in the presence of a test sample (e.g., chemical, mixture of chemicals, or extract of an environmental sample) to the number of colonies in the absence of the test sample. Since growth occurs in proportion to mutagenic potential, growth will be greater in the presence of a mutagen, and will increase as the dose of mutagen is increased. The increase in growth in response to dose is depicted graphically in dose-response curves. The minimum mutagenic ratio (ratio of number of colonies that form in the presence of a test sample to the number of colonies on a control growth plate) is 2.0. Therefore, a sample exhibiting a mutagenic ratio greater than 2.0 is considered to possess mutagenic properties.

A study to evaluate detoxification of mutagenic potential of a complex fossil fuel waste containing PAH compounds treated in a soil system was conducted utilizing the Ames assay [67]. Mutagenic ratios for *S. typhimurium* strain TA98 (a test strain used to detect frameshift mutagens such as PAHs) with metabolic activation (to simulate mammalian metabolism by the addition of a mammalian liver extract (referred to as the S9 fraction)). and without metabolic activation (without the addition of the S9 fraction) were determined immediately after waste incorporation and after 42 days of incubation of the waste in the soil. Results as shown in dose response curves showed that the mutagenic ratios decreased from about 4.5 and 7.0 at the highest dose levels tested immediately after waste incorporation (Figure 5) to borderline mutagenic levels (i.e., mutagenic ratios of about 2) after 42 days of treatment (Figure 6). For a different *S. typhimurium* strain, (TA100, a test strain used to detect mutagens causing base-pair substitutions), no dose-response effects or mutagenic activity were measured during the study.

Results of a pilot scale field study have also demonstrated that bioremediation of PAH contaminated soils is a technology that can result in significant cleanup of contaminated soils [69]. A coal gasification waste was thoroughly mixed into a soil at a one-half acre site. Sampling of soil cores was performed at 10 feet intervals across 100 feet rows. Data presented in Table 10 are composite values from the sampling efforts. In all cases, concentrations of the PAH compounds in the soil were greatly reduced after 91 days. Data quality was poorer at the 91-day sampling period, as measured by the coefficient of variation (CV), which is the mean value measured (AVG) divided by the standard deviation (SD). The poorer data quality was attributed to increased analytical difficulties when levels of constituents near detection limits are measured.

The fate and environmental impact of transformation products is an area of bioremediation that needs more consideration. In a laboratory study, the transformation of a ^{14}C radio-labelled PAH compound, 7,12- dimethylbenz(a)-anthracene, in a sandy loam soil was investigated for a 28-day incubation period [70]. At time 0, 62% of the applied parent compound was recovered from the soil, which represents the extraction efficiency of the test (Table 11). After 28 days of incubation, only 20% of the parent compound was recovered. Since recoveries in control reactors poisoned with mercuric chloride were not significantly different over the 28-day incubation period, biological treatment was the proposed mechanism of compound removal from the soil system. Table 11 also shows that the decrease in parent ^{14}C was accompanied by an increase in the metabolite ^{14}C fraction. The appearance of transformation products increased from 4% of the total ^{14}C applied at time 0 to 53% after 28 days. None of the radiolabelled carbon appeared as CO_2 in this study, but 12 to 17% of the radiolabelled material was associated with the solid phase of the soil during the incubation period. The mass balance for the study ranged from 78 to 90% recovery of the applied radiolabelled carbon. Therefore, the appearance, toxicity, fate, and behavior of a metabolite fraction may need to be evaluated on a site-specific basis.

The environmental significance and fate and behavior of many transformation products of PAH constituents, as well as transformation products from many other organic constituents, are not yet known. Therefore, incorporating detoxification assessment into a bioremediation plan is recommended to evaluate these concerns.

Table 10. Field Results for Soil Treatment of PAHs in Coal Gasification Wastes [69]

Compound	C_o*(µg/g)			C After 91 days (µg/g)		
	AVG	SD	CV(%)	AVG	SD	CV(%)
Naphthalene	186	68	37	3	1.8	61
Acenaphthene	729	276	38	1	1.8	157
Phenanthrene	78	28	36	2.6	0.6	23
Benz(a) anthracene	86	42	49	2	0.8	38
Dibenz(a,h) anthracene	52	36	69	ND	--	--

*C_o = Initial Soil Concentration

Table 11. Transformations of (^{14}C) DMBA by McLaurin Sandy Loam Soil* [70]

	^{14}C appearing in each fraction, percent				
	Soil extract				
Time, days	DMBA, parent compound	Metabolites	Soil Residue	CO_2	Total
0	62(69)	4(6)	12(13)	0(0)	78(88)
14	26	43	16	0	85
28	20(60)	53(11)	17(16)	0(0)	90(87)

* Poisoned (control) data in parentheses.

Table 12. Wood Preserving Sites Where Bioremediation has been Proposed for Soil or Lagoon Sediments [71]

Site Name	State (U. S. EPA Region)	Proposed Remediation
L.A. Clark and Son	VA (III)	Bioremediation
Brown Wood Preserving	FL (IV)	Bioremediation
Burlington Northern (Brainard)	MN (V)	Landfarm
North Cavalcade Street	TX (VI)	Bioremediation
United Creosoting Company	TX (VI)	In Situ remediation
Baxter/Union Pacific	WY (VIII)	Bioremediation
Burlington Northern Somers)	MT (VIII)	Landfarm
Libby (Champion International)	MT (VIII)	In Situ Bioremediation and Landfarm
Koppers, Co.	CA (IX)	Bioremediation
J.H. Baxter	CA (IX)	Bioremediation

9. Implementation of Bioremediation at Sites Contaminated with Organic Wastes

A recent survey conducted for the U.S. EPA concerning the use of bioremediation at sites with soils contaminated with wood-preserving wastes identified ten sites that currently plan to use bioremediation techniques to cleanup contaminated soils and sediments (Table 12) [71]. Sims observed a wide range of variability in target clean-up levels. A wide variability also was observed in criteria for selecting target levels (maximum contaminant levels (MCLs) based on drinking water standards vs. negotiated levels vs. risk assessment-based levels) and in selection of soil phases that must meet target levels (solid phase, leachate phase, and/or air phase). Target levels were determined on a site-specific basis.

An example of a bioremediation plan for a facility identified in the survey was presented by Lynch and Genes [72]. On-site treatment of creosote-contaminated soils from a shallow, unlined surface impoundment was demonstrated at a disposal facility for a wood-preserving operation in Minnesota. The contaminated soils contained creosote constituents consisting primarily of PAHs at concentrations ranging from 1,000 to 10,000 ppm. Prior to implementation of the full scale treatment operation, bench-scale and pilotscale studies simulating proposed full-scale conditions were conducted to define operation and design parameters. Over a four-month period, 62% to 80% removal of total PAHs were achieved in all test plots and laboratory reactors. Two-ring PAH compounds were reduced by 80-90%, 3-ring PAHs by 82-93%, and 4+-ring PAHs by 21-60%.

The full-scale system involved preparation of a treatment area within the confines of the existing impoundment. A lined waste pile for temporary storage of the sludge and contaminated soil from the impoundment was constructed. All standing water from the impoundment was removed, and the sludges were excavated and segregated for subsequent free oil recovery. Three to five feet of "visibly" contaminated soil was excavated and stored in the lined waste pile. The bottom of the impoundment was stabilized as a base for the treatment area. The treatment area was constructed by installation of a polyethylene liner, a leachate collection system, four feet of clean backfill, and addition of manure to achieve a carbon:nitrogen ratio of 50:1. A sump for collection of stormwater and leachate and a center pivot irrigation system were also installed. The lined treatment area was required because the natural soils at the site were highly permeable. A cap was also needed for residual contaminants left in place below the liner. Contaminated soil was periodically applied to the treatment facility and roto-tilled into the treatment soil. Soil moisture was maintained near field capacity with the irrigation system. During the first year of operation, greater than 95% reductions in concentration were obtained for 2- and 3-ring PAHs. Greater than 70% of 4- and 5-ring PAH compounds were degraded during the first year. Comparison of half-lives of PAHs in the full-scale facility were in the low end of the range of half-lives reported for the test plot units. Only two PAH compounds were detected in drain tile water samples, at concentrations near analytical detection limits.

Bioremediation of a Texas oil field site with storage pit backfill soils contaminated with styrene, still bottom tars,

and chlorinated hydrocarbon solvents was demonstrated on a pilot scale [73]. The remediation efforts also included chemical and physical treatment strategies. The pilot scale, solid-phase biological treatment facility consisted of a plastic film greenhouse enclosure, a lined soil treatment bed with an underdrain, an overhead spray system for distributing water, nutrients, and inocula, an organic vapor control system consisting of activated carbon absorbers, and a fermentation vessel for preparing microbial inoculum or treating contaminated leachate from the backfill soils. Soils were excavated from the contaminated area and transferred to the treatment facility. Average concentrations of volatile organic compounds (VOCs) were reduced by more than 99% during the 94 day period of operation of the facility; most of the removal was attributed to air stripping. Biodegradation of semivolatile compounds reduced average concentrations by 89% during the treatment period.

A solid-phase treatment system to remediate petroleum contaminated soil at a hazardous waste site in California was described by Ross et al. [6]. The treatment process involved stimulating the existing microbial population in the soil to degrade petroleum hydrocarbon contaminants. A biotreatability evaluation prior to full-scale operation demonstrated that the existing microorganisms in the soil could degrade the petroleum hydrocarbons, but that the nutrient levels in the soil were not sufficient to maintain growth and support complete degradation of the hydrocarbon contaminants. With adequate nutrients, hydrocarbons decreased from 3500 ppm to less than 100 ppm in 4 weeks in bench scale studies. The degradation process exhibited biphasic kinetics, likely due to the fact the petroleum hydrocarbons were a mixture of a lighter diesel fuel and more recalcitrant waste motor oils. The full scale facility, which began operation in 1988, consists of a four acre treatment site that has had 30 inches of contaminated soil applied to the surface. Bioremediation of the top 15 inches was proceeding by the addition of nutrients, daily tilling and maintenance of adequate soil moisture levels. When the first 15 inches of contaminated soil have been remediated to the target cleanup level of 100 ppm, it will be removed and the second 15 inches will be treated. During the first four weeks of operation, the average concentration of petroleum hydrocarbons was reduced from 2,800 to 280 mg/kg. The rate of hydrocarbon biodegradation measured in the field was consistent with the rate measured in the laboratory.

A solid phase treatment system to clean up pesticides in soil contaminated as a result of a fire at a chemical storage facility was also described by Ross et al. [6]. Water used to extinguish the fire carried large amounts of insecticides and herbicides into the soil beneath the warehouse facility. Laboratory biotreatability studies showed that moderately contaminated soils (90 mg/kg of 2,4-D) could be treated in a soil treatment system to meet regulatory criteria (total MCPA and 2,4-D = 10 mg/kg), while highly contaminated soils (2,4-D concentrations greater than 200 mg/kg) required treatment in a soil/water slurry bioreactor. A five acre soil treatment area was constructed with an engineered clay liner 12 inches thick and a drainage system to control water movement. Ten thousand cubic yards of soil contaminated with a complex mixture of herbicides and insecticides, including 2,4-D, alachlor, trifluralin, carbofuran, and MCPA, were spread on the treatment bed to an average depth of 15 inches. During operation, soil conditions were optimized for biological activity by daily tilling and by maintenance of soil moisture content between 8% and 15% by weight. During three months of operation, the combined 2,4-D and MCPA concentrations decreased from 86 ppm to 5 ppm.

Brubaker and Exner [74] reported on two case histories that involved microbial degradation of chemical contaminants to remediate chemical spills. Both sites also involved other remediation tools in addition to microbial remediation, emphasizing the need to examine complementary and synergistic remediation techniques. At the first site, residual contamination from a formaldehyde spill was treated using chemical oxidation with hydrogen peroxide, followed by microbial "polishing" to complete the remediation. A commercial inoculum of microorganisms acclimated for formaldehyde degradation and a nutrient solution were mixed in an aeration tank and then sprayed on the site. Water was collected in a sump and recycled through the aeration tank. Treatment effectiveness was measured by reduction of concentration of formaldehyde in the aeration tank. After 25 days, concentrations had dropped from over 700 mg/l to less than 1 mg/l. At the second site, a gasoline leak from an underground storage tank was remediated with enhanced bioreclamation techniques, which consisted of addition of nutrients and hydrogen peroxide as an oxygen source. A series of injection and recovery wells were used to recycle water through the site. Soil samples showed a decrease in volatile fuel hydrocarbons from an average of 245 ppm at the initiation of the bioreclamation process to 0.8 ppm after 200 days.

Bioremediation of a site contaminated with PCBs, which have generally been considered resistant to biodegradation in the environment, has been demonstrated at a drag-racing track in New York [55]. Laboratory treatability studies using contaminated soils from the sites inoculated with pure resting cell cultures of PCB-degrading organisms that had been isolated from environmental samples showed substantial PCB biodegradation, up to 51% of the PCBs present in three days. Follow-up laboratory studies were conducted using only 3-4% of the number of cells used in the earlier studies, lower moisture content, lower temperatures, and no shaking or aeration of the reaction mixtures. PCB degradation was not observed until 30 days after the initiation of the study. In an undisturbed soil sample inoculated three times weekly with the PCB-degrading microorganisms, 50% of the PCBs in the top 1 cm of soil was degraded in 15 weeks. Only 10% degradation was seen at depths below 1 cm. When a duplicate of the undisturbed soil experiment was mixed at three months with continued inoculation, the redistributed soil again exhibited the highest degradation rate at the surface. In experiments where soils were inoculated three times weekly and mixed after each application, 35% of the PCBs were degraded after 23 weeks at all depths. This degree of degradation represents a greater amount of PCB

destruction since the PCBs were degraded throughout the whole sample and not just at the surface. Thus mixing was identified as an important site management variable. Preliminary results at a field scale test site at the drag-racing track indicated significant PCB degradation after eight to ten weeks.

10. Conclusions

Consideration of bioremediation for remediation of a site contaminated with organic constituents requires a detailed site, soil, and waste characterization that must be conducted in order to evaluate the potential application of the technology at the site and to demonstrate the feasibility of the approach. A sound and thorough engineering remediation plan developed at the onset of the project will allow cost-effective and efficient use of resources for implementation of site clean-up. The use of treatability studies and simulation modeling are also necessary components of the bioremediation plan so that necessary data to evaluate potential use and to identify pathways of migration are collected in a cost-effective manner. Bioremediation of sites contaminated with organic chemicals is a promising technology, especially if it is incorporated in a remediation plan that uses an integrated approach to the cleanup of the complete site, i.e., a plan that involves the concept of a "treatment train" of physical, chemical, and/or biological processes to address remediation of all sources of contaminants at the site.

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Note: A more comprehensive bibliography is being developed.

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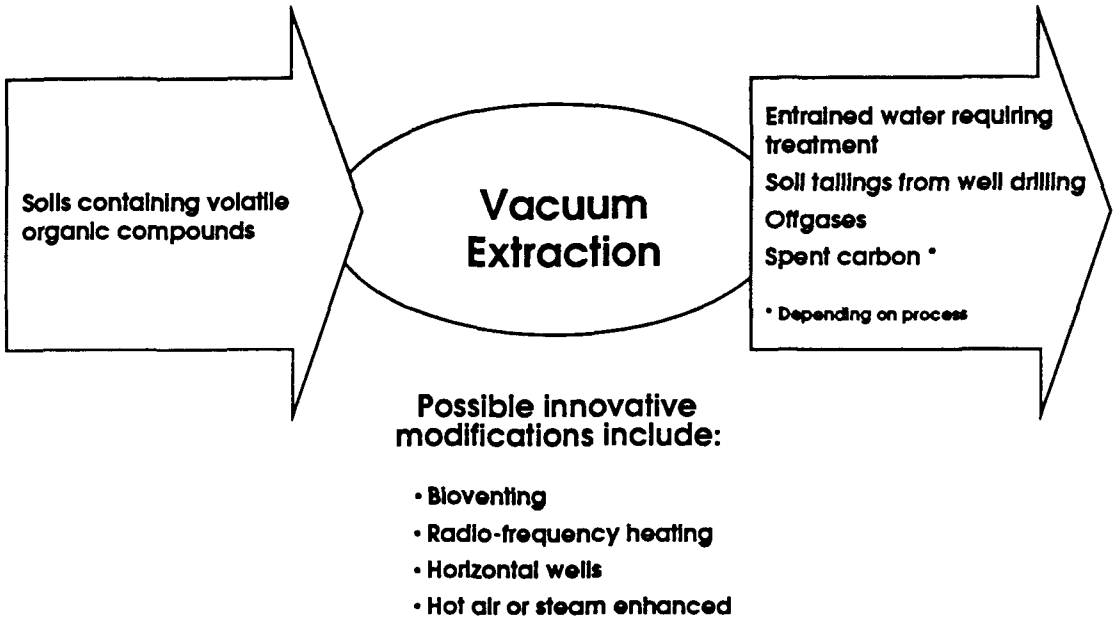
8.0 VACUUM EXTRACTION

8.1 TECHNOLOGY DESCRIPTION

This system applies a vacuum to a series of extraction wells to create air flow through the vadose zone. As air moves through the system, volatile contaminants move from the soil and pore water to the air. The contaminated air is withdrawn, often with entrained water, and treated using an emission control system such as activated carbon or catalytic oxidation.



8.2 TECHNOLOGY STATUS

- Used at over 50 sites, including eleven Superfund sites, where the application is complete (one site) or in progress (ten sites). A SITE demonstration at the Groveland Wells Site in Massachusetts was also conducted to evaluate the effectiveness of the process.

8.3 APPLICATION

- In practical terms, the process works well with most soil types. In a SITE demonstration, the process demonstrated good performance in removing volatile organics from soil with measured permeability ranging from 10^{-4} to 10^{-8} cm/s.
- The process works well under all weather conditions.
- The process is generally applicable to volatile and moderately volatile organic compounds.

- The vapor pressure of the compound provides a relative measure of the volatility. Exhibit 4 presents the vapor pressures of organic compounds frequently found at Superfund sites. Although the success of a vacuum extraction project will depend on site specific conditions, this technology has been selected for contaminants with vapor pressures as low as 8 torr.

- The technology is also applicable for removal of volatile light non-aqueous phase liquids floating on the water table or entrained in the capillary fringe.

8.4 TECHNOLOGY STRENGTHS

- Can be used in conjunction with other remedial alternatives. Can be used as pretreatment prior to excavation.

- Demonstrated effectiveness in removing VOCs from the vadose zone.

- Minimally disturbs contaminated soil.

- Treatment costs are low compared to technologies requiring excavation. Available data indicate costs typically near $50 per ton. The economics of this process strongly depend on whether off-gas treatment is required and whether wastewater is generated at the site. These factors were considered in the above estimate. The most cost effective systems have been in homogeneous, sandy soils.

- The technology is relatively simple and reliable.

8.5 TECHNOLOGY LIMITATIONS

- The process is limited to volatile compounds.

- Non-homogeneous soil can result in irregular air flow or "short circuiting" which will result in uneven treatment.

- Entrained soil moisture must be removed from the air stream and treated. When the soil moisture is high, this can add to the cost of treatment.

8.6 POTENTIAL MATERIALS HANDLING REQUIREMENTS

- This technology is used in situ; no excavation is required.

- The contaminated soils may require dewatering. Because this technology works better as the air-filled porosity of the soils increases, performance may be improved and removal of the contaminants maximized early in treatment by dewatering saturated or very wet areas before treatment. Because this is an in situ technology, the material must be dewatered with in situ methods such as well points and drains.

8.7 WASTE/SOLID CHARACTERISTICS AFFECTING PERFORMANCE

- The major considerations in applying this technology are contaminant volatility, air-filled soil porosity, and site-specific cleanup level.
- Where soils have low permeability and high moisture content (i.e., low air-filled porosity) a pilot demonstration test should be considered to determine the feasibility of dewatering the soil.
- There is ongoing testing of alternatives to activated carbon for exhaust air treatment. One such system involves thermal catalytic destruction.

8.8 BIOVENTING

A promising modification of vacuum extraction is its potential to enhance the biodegradation of volatile and semivolatile chemicals in the soil. Vacuum extraction provides air to the vadose zone, and thus carries oxygen that can be used by soil microorganisms to biodegrade contaminants. Field tests conducted by the Air Force in 1990 at Tyndall Air Force Base on soils contaminated with jet fuel suggest that biodegradation becomes increasing significant as the primary hydrocarbon removal mechanism as the more volatile compounds are stripped from the soil. Under optimal air flow conditions (0.5 air void volumes per day), 82% of the hydrocarbon removal was the result of biodegradation. These field tests also suggest that the effect of temperature on biodegradation rates approximates the effects predicted by the van't Hoff-Arrhenius equation, i.e., the reaction rate approximately doubles for every 10°C rise in temperature.

This modification of the process has two potential benefits. First, it will supply complete destruction of a large portion of contaminants in the ground and minimize the amount of extracted gas requiring treatment, thereby reducing costs. Second enhanced in situ biodegradation will also destroy the heavy hydrocarbons that, due to their low volatility, are not removed by conventional vacuum extraction alone.

8.9 RADIO-FREQUENCY HEATING

Another potential enhancement of the vacuum extraction process is the use of radio-frequency (RF) heating to more rapidly volatilize contaminants and to increase the volatilization of compounds with higher boiling points. The uniform heating provided by RF energy is also expected to improve soil porosity and to improve removal rates in clay and silt soils.

This technology is being demonstrated by the Air Force. Energy is delivered by means of an array of electrodes placed in bore holes. The specific frequency is selected based on dielectric properties of the soil, the depth of treatment desired, and the size of the heated soil volume. Recent tests were conducted on a fire training area at an Air Force base in Wisconsin. A 500 ft^3 test volume was heated for 12 days. The first 8 days were required to heat the soil to the 300°F 150°C target temperature, which was then retained for a period of 4 days. A 97 percent removal was observed for semivolatile hydrocarbons and a 99 percent removal for volatile aromatics and aliphatics. Power estimates for full-scale application were quite reasonable at 500 kw-hr/yd^3.

8.10 STEAM OR HOT AIR INJECTION

In situ steam injection facilitates the removal of moderately volatile residual organics, including NAPLs, from the vadose zone. Steam injection technology injects pressured steam to thermally enhance the evaporation rate of the contaminant and its subsequent removal. Injection of steam also can be expected to enhance removal of residual NAPL's in the unsaturated zone by decreasing their viscosities. Steam injection is an emerging technology that appears promising, particularly if used in conjunction with vacuum extraction.

8.11 HORIZONTAL WELLS FOR IN SITU REMEDIATION (Discussed in Section 10.4)

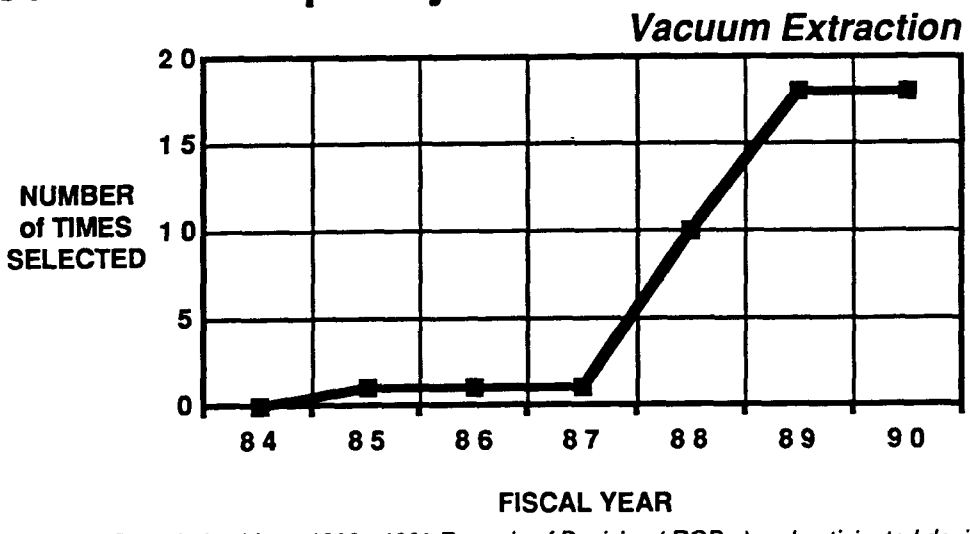
8.12 EXHIBIT 1 - WASTE CHARACTERISTIC TABLE

Waste Type: Soils
Technology: In Situ Vacuum and Steam Extraction

Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Presence of: • Less volatile organics • Metals • Cyanides • Inorganics	Only volatile compounds with a Henry's Law constant of approximately >3 x 10^{-3} atm-m/mole can be effectively removed by vacuum extraction; theoretically, steam or hot air extraction should apply to less volatile compounds.	Analysis for priority pollutants; Henry's Law constant or vapor pressures for organics
High solubility of volatile organics in water	Dissolved organics are more mobile and harder to remove from aqueous phase.	Contaminant solubilities
Unfavorable soil characteristics:		
• Low permeability	Hinders movement of air through soil matrix.	Percolation test, pilot vapor extraction tests
• Variable soil conditions	Inconsistent removal rates.	Soil mapping
• High humic content	Inhibition of volatilization.	Analysis for organic matter
• High moisture content	Hinders movement of air through soil.	Analysis of soil moisture content

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

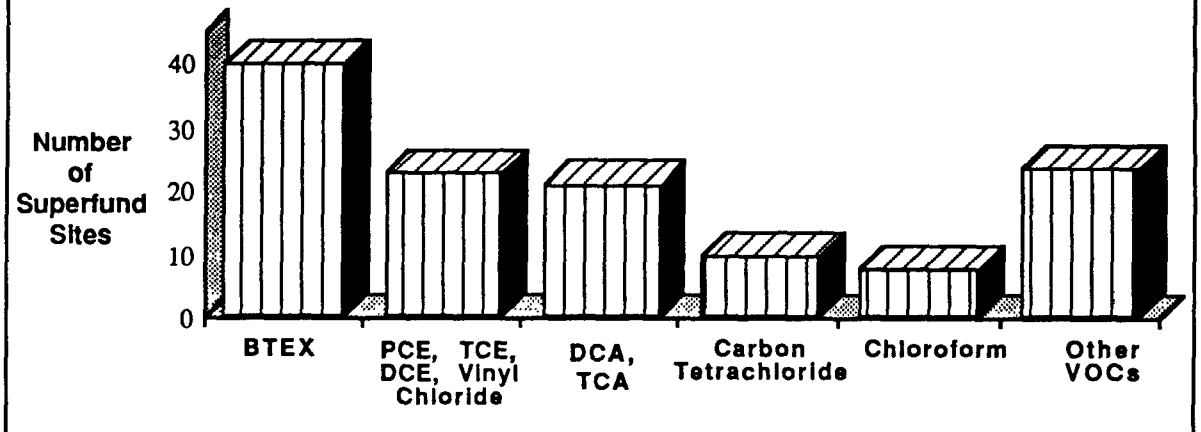
Selection Frequency*



* *Data derived from 1982 - 1990 Records of Decision (RODs) and anticipated design and construction activities.*

September 1991

Contaminants Treated By Vacuum Extraction



* *Data derived from 1982 – 1990 Records of Decision (RODs) and anticipated design and construction activities. At some sites, the treatment is for more than one major contaminant.*

Vacuum Extraction

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
1	Groveland Wells, MA* (09/30/88)	Vapor Extraction	Manufacturing	Soil (19,000 cy)	VOCs (TCE, Methylene Chloride, and 4-methyl-2-pentanone)	In design;	PRP Lead	Bob Leger 617-573-5734 FTS 833-1734
1	Kellogg-Deering Well Field, CT (09/29/89)	Vacuum Extraction	Municipal Landfill	Soil (quantity not available)	VOCs (TCE, PCE, BTEX, DCE, TCA, DCA, and Vinyl Chloride)	In design; Design completion planned Summer '92	PRP Lead	Leslie McVickar 617-573-9689 FTS 833-1689
1	South Municipal Water Supply Well, NH (09/27/89)	Vacuum Extraction	Commercial Manufacturing	Soil (7,500 cy)	VOCs (PCE, TCA, and TCE)	In design; Design completion planned Summer '92	PRP Lead	Roger Duwart 617-573-9628 FTS 833-1628
1	Stamina Mills, RI (09/28/90)	Vacuum Extraction	Textile Manufacturing	Soil (6,000 cy) (to 12' depth)	VOCs (DCE and TCE)	Predesign	PRP Lead	Neil Handler 617-573-9630 FTS 833-1630
1	Tinkham Garage, NH* (09/30/86)	Vacuum Extraction	Uncontrolled Dump Site	Soil (9,000 cy)	VOCs (Benzene, Chloroform, DCE, PCE, TCE, and Vinyl Chloride)	In design; Design completion planned Fall '91	PRP Lead; Terra Vac	Diana King 617-573-9676 FTS 833-1676
1	Wells G&H, MA (09/14/89)	In situ Volatilization	Uncontrolled Dump Site	Soil (7,400 cy)	VOCs (PCE and TCE)	In design	PRP Lead	Barbara Newman 617-573-5736 FTS 833-1736
2	FAA Technical Center, NJ (09/26/89) Also see Bioremediation (In situ)	Vacuum Extraction	Jet Fuel Farm	Soil (33,000 cy)	VOCs (BTEX), SVOCs (Chlorophenol, Phenol), PAHs	In design; Design completion planned 9/91	PRP Lead	Carla Struble 212-264-4595 FTS 264-4595 Keith Buch (FAA) 609-484-6644
2	SMS Instruments (Deer Park), NY (09/29/89)	Vapor Extraction	Military Aircraft Component Overhauler	Soil (1,250 cy) (to 25' depth)	VOCs (TCE, Xylene, Ethylbenzene, and Chlorobenzene)	Cleanup contract award scheduled for 9/91	Fund Lead	Miko Fayon 212-264-4706 FTS 264-4706

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Vacuum Extraction

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
2	Upjohn Manufacturing Co., PR (09/30/88 for gw; treatment completed prior to ROD)	Vacuum Extraction	Industrial Facility, Chemical Leak	Soil (quantity not available)	VOCs (Carbon Tetrachloride and Acetonitrile)	Project completed; operational late 1984 - to 3/88	PRP Lead; Terra Vac	Alison Hess 212-264-6040 FTS 264-6040
2	Vestal Water Supply 1-1, NY (09/27/90)	Vacuum Extraction	2 Areas within an Industrial Park	Soil; Area (1) 19,000 cy; Area (2) 6,000 cy	VOCs (DCA, TCA, TCE, and DCE)	Predesign; Design completion planned Summer '92	Area (1) PRP Lead Area (2) Fund Lead	Ed Als 212-264-0522 FTS 264-0522
3	Bendix, PA (09/30/88)	Vacuum Extraction	Aircraft Manufacturing	Soil (quantity not available)	VOCs (TCE, Toluene, Vinyl Chloride, DCE, and Carbon Tetrachloride), and SVOCs	In design; Design completion planned Fall '92	PRP Lead	Humane Zia 215-597-0913 FTS 597-0913
3	Henderson Road, PA* (06/30/88)	In situ Volatilization	Injection Well	Soil (quantity not available)	VOCs (BTEX, Chlorobenzenes, DCA, and 1,1,1-TCA)	In design; Design completion planned Fall '91	PRP Lead	Michael Towle 215-597-3166 FTS 597-3166
3	Lord-Shope Landfill, PA (06/29/90)	Vacuum Extraction	Industrial Drum Landfill	Soil/source (approxi-mately 50,000 cy; to 15' depth)	VOCs (Benzene, PCE, and Toluene)	Predesign	PRP Lead	Jim Feeney 215-597-8257 FTS 597-8257
3	Tyson's Dump, PA* (03/31/88)	Vacuum Extraction	Commercial Surface Impoundment	Soil (30,000 cy)	VOCs (Benzene, Toluene, TCE, PCE, and Trichloropropane)	Operational since 11/88	PRP Lead; Terra Vac	Eugene Dennis 215-597-8555 FTS 597-8555
4	Hinson Chemical, SC (Emergency Response - AM signed 11/28/88)	Vacuum Extraction with In situ Flushing with Air	Waste Reclaiming Facility	Soil (≈80,000 cy; to 50' depth)	VOCs	Process ongoing 12/88 - present	Fund Lead	Fred Stroud 404-347-3136 FTS 257-3136
4	Jadco-Hughes, NC (09/27/90) Also see In situ Flushing	Vacuum Extraction (followed by in situ soil flushing)	Solvent Recovery and Storage Facility	Soil (6,000 cy)	VOCs (Carbon Tetra-chloride, Chloroform, and Vinyl Chloride) and SVOCs (Dichlorobenzene)	In design; Design completion planned Winter '93	PRP Lead	Barbara Benoy 404-347-7791 FTS 257-7791

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Vacuum Extraction

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
4	SCRDI Bluff Road, SC (09/12/90)	Vacuum Extraction	Solvent Reclamation	Soil (29,500 cy)	VOCs (Carbon Tetrachloride, Acetone, Chloroform, TCA, DCA, PCA, PCE, TCE, DCE, Methylene Chloride, 2-Butanone, BTEX, 4,methyl-2,pentanone, Vinyl Chloride)	Predesign; Design completion planned Summer '92	PRP Lead	Steve Sandler 404-347-2643 FTS 257-2643
5	Fisher Calo Chem, IN (08/07/90)	Vapor Extraction	Solvent Reclamation	Soil (29,500 cy)	VOCs (PCE, DCA,and TCA)	Predesign; Design completion planned Spring '93	Fund Lead	Brad Bradley 312-886-4742 FTS 886-4742
5	Hagen Farm, WI (09/17/90)	Vapor Extraction (evaluating effectiveness of vapor extraction in enhancing bioremediation of SVOCs)	Industrial and Municipal Waste Disposal	Soil/Waste (24,000 cy)	VOCs (BTEX, Butanone, Tetrahydrofuran, and Vinyl Chloride)	Pilot Test scheduled for Winter '91 - Design completion planned Summer '92	PRP Lead	Jay Lee 312-886-4749 FTS 886-4749 Don DiGiulio (RSKERL) 405-332-8800 FTS 743-2011
5	Kysor Industrial, MI (09/29/89)	Vacuum Extraction	Truck Parts Manufacturing	Soil (13,200 cy)	VOCs (Xylene, Toluene, Ethylbenzene, and TCE)	In design; Design completion planned Summer '92	PRP Lead (RD); RA in negotiation	Mary L. Gustafson 312-886-6144 FTS 886-6144
5	Long Prairie, MN (06/27/88)	Vacuum Extraction	Dry Cleaning Facility	Soil (3,600 cy)	VOCs (DCE, PCE, TCE, and Vinyl Chloride)	Cleanup contract award scheduled for Fall '91.	State Lead/Fund Financed	Kevin Turner 312-886-4444 FTS 886-4444
5	MIDCO I, IN* (06/30/89)	Vapor Extraction	Commercial Dump Site	Soil (12,400 cy)	VOCs (BTX, TCE, Phenol, Dichloromethane, 2-Butanone, and Chlorobenzene), PAHs, and SVOCs	Predesign	Fund Lead/In Negotiation	Richard Boice 312-886-4740 FTS 886-4740

* Indicates that a treatability study has been completed.

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Vacuum Extraction

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
5	Miami County Incinerator, OH (06/30/89)	Vapor Extraction	Municipal Landfill and Surface Impoundment	Soil (98,000 cy)	VOCs (TCE, PCE, and Toluene)	Predesign	PRP Lead	Anthony Rutter 312-886-8961 FTS 886-8961
5	Pristine (Amendment), OH (03/30/90)	Vapor Extraction (Replaces in situ vitrification)	Commercial Dump Site	Soil (quantity unknown - to 12' depth)	VOCs (Benzene, Chloroform, Dichloroethane, PCE, and TCE) and SVOCs (Phenol)	Predesign	PRP Lead; Hydrogeo-Chem	Thomas Alcamo 312-886-7278 FTS 886-7278
5	Seymour Recycling, IN* 05 (09/30/87) Also see Bioremediation (In situ)	Vacuum Extraction	Chemical Waste Management & Incineration	Soil (154,000 cy)	VOCs (TCA, Carbon Tetrachloride, PCE, Benzene, Vinyl Chloride, Chloroethane, and TCE)	Operational since April 1991	PRP Lead; Canonie Engineering (Installation), Geraghty & Miller (Operation)	Jeff Gore 312-886-6552 FTS 886-6552
5	Springfield Township Dump, MI (09/29/90)	Vacuum Extraction	Industrial Waste Dump	Soil (100,000 cy)	VOCs (Butanone, Chlorobenzene, TCA, TCE, and Toluene)	Predesign	PRP Lead	Mary Lou Martin 312-353-6284 FTS 353-6284
5	Verona Well Field, MI* (08/12/85)	Vacuum Extraction	Railroad Paint Shop, Solvent Reclaiming/ Distribution	Soil (35,000 cy)	VOCs (Dichloromethane, Chloroform, Carbon Tetrachloride, DCA, TCA, Vinyl Chloride, and BTEX) and Naphthalene	Operational since 3/88	Fund Lead; Terra Vac (subcontractor to CH2M-Hill)	Margaret Guerriero 312-886-0399 FTS 886-0399
5	Wausau Groundwater Contamination, WI* (09/29/89)	Vapor Extraction	Bulk Chemical Distribution, Machine Shop	Soil (1,300 cy)	VOCs (TCE, PCE, and DCE)	In design; Design completion planned Spring '92	PRP Lead; Hydrogeo-Chem	Margaret Guerriero 312-886-0399 FTS 886-0399
5	Wayne Waste Reclamation, IN (03/30/90)	Vapor Extraction	Dump Site	Soil (300,000 cy - approximately 10 acres to 20' depth)	VOCs (TCE, DCE, BTEX, and Vinyl Chloride)	Predesign	PRP Lead	Tinka Hyde 312-886-9296 FTS 886-9296
6	South Valley/Edmunds, NM (09/30/88)	Vapor Extraction	Aircraft Engine Manufacturing	Soil (36,000 cy)	VOCs (TCE)	In Design; Start planned 11/91	PRP Lead	Tim Underwood 214-655-6730 FTS 255-6730

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Vacuum Extraction

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
6	Tinker AFB (Soldier Creek/Bldg. 3001), OK (08/16/90)	Vacuum Extraction	Maintenance Facility for Aircraft	Soil (quantity not available)	VOCs (TCE, Acetone, Chlorobenzene, Ethylbenzene, Methylene Chloride, Styrene, Toluene, and Xylene)	Predesign; Design completion planned Summer '92	PRP Lead (Air Force)	Susan Webster 214-655-6730 FTS 255-6730
7	Hastings Groundwater Contamination, Colorado Ave., NE* (09/28/88)	Vapor Extraction	Industrial Metal Finishing	Soil (42,700 cy)	VOCs (PCE, TCE, and TCA)	In design	PRP Lead	Darrel Sommerhauser 913-551-7711 FTS 276-7711
7	Hastings Groundwater Contamination, Far-Mar-Co, NE* (09/30/88)	Vapor Extraction	Former Grain Storage Area (Fumigants)	Soil (400 cy)	VOCs (Carbon Tetrachloride and Ethylene Dibromide)	In design; Design completion planned Spring '92	PRP Lead	Susan Hoff 913-551-7786 FTS 276-7786
7	Hastings Groundwater Contamination, Well No. 3, NE* (09/26/89)	Vapor Extraction	Former Grain Storage Area (Fumigants)	Soil (quantity not available) (7 extraction wells planned)	VOCs (Carbon Tetrachloride and Chloroform)	In design; Design completion planned Fall '91; Construction bid package to be advertised Fall '91.	Fund Lead	Diane Easley 913-551-7797 FTS 276-7797 Steve Roe (Morrison Knudsen) 303-793-5054
7	Lindsay Manufacturing, NE (09/28/90)	Vapor Extraction	Metal Finishing Site	Soil (to 50' depth)	VOCs (DCA, DCE, TCE, and PCE)	Predesign	PRP Lead	Cecelia Tapia 913-551-7052 FTS 276-7052
7	Waverly Groundwater Contamination, NE (09/26/90)	Vapor Extraction	Grain Storage (Fumigants)	Soil (5 acres to 10 - 20 feet deep)	VOCs (Carbon Tetrachloride and Chloroform)	System Operating since 2/88	PRP Lead (USDA)	Gene Gunn 913-551-7776 FTS 276-7776
8	Martin Marietta (Denver Aerospace), CO (09/24/90) Also see Thermal Desorption	Vapor Extraction	Aerospace Equipment Manufacturer	Soil	VOCs (TCE)	Predesign	State Lead (under RCRA Corrective Action Authority)	George Dancik 303-293-1506 FTS 330-1506

* Indicates that a treatability study has been completed.

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Vacuum Extraction

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
8	Rocky Mountain Arsenal (OU 18), CO (02/26/90)	Vapor Extraction	Federal Facility	Soil (4,000 cy)	TCE	Initial design completed 1/91 Pilot study underway; may modify design	PRP Lead (U.S. Army)	Linda Jacobson 303-294-1977 FTS 330-1977
8	Sand Creek Industrial (OU1), CO* (09/29/89)	Vacuum Extraction	Refinery, Pesticides Manufacturing, Acid Dilution Company, and Landfill	Soil (>100,000 cy)	VOCs (TCE, PCE, Methylene Chloride, and Chloroform)	Design completed; will install after NAPLs addressed	Fund Lead; URS	Brian Pinkowski 303-293-1512 FTS 330-1512 John Chinnook (URS) 303-796-9700
9	Motorola 52nd Street, AZ* (09/30/88)	Vapor Extraction	Manufacturing Facility	Soil (60' radius to 25' depth)	VOCs (TCA, TCE, PCE, Carbon Tetrachloride, and Ethylbenzene)	In design; pilot test planned for Summer '91	PRP Lead/ State Oversight; Dames and Moore	Mike Montgomery 415-744-2394 FTS 484-2394 Don Atkinson (AZ) 602-257-6899
9	Phoenix-Goodyear Airport Area (North Facility and South Facility), AZ* (09/26/89)	Vapor Extraction	Defense-related Manufacturing Facility	Soil; North Facility (140,000 sq. ft. to 50 ft. depth) 260,000 cy; South Facility 870 cy	North Facility VOCs (TCE, Methylethyl Ketone, Acetone) South Facility VOCs (TCE, TCA)	In design; Design completion planned North - Spring 1992 South - Fall 1992	PRP Lead	Craig Cooper 415-744-2370 FTS 484-2370
9	Fairchild Semiconductor (San Jose), CA* (03/20/89)	Vapor Extraction	Semiconductor Manufacturing Facility	Soil (3,400 cy)	VOCs (TCA, Xylenes, Acetone, Freon, DCE, and PCE)	Operational since 1988	PRP Lead/ State Enforcement; Canonie Engineering	Helen McKinley 415-744-2236 FTS 484-2236 Will Bruhns (CA) 415-464-0838
9	Fairchild Semiconductor/ MTV-I, CA* (06/09/89)	Vapor Extraction	Semiconductor Manufacturing Facility, Metal Finisher	Soil (quantity not available)	VOCs (TCE, PCE, Vinyl Chloride, DCA, DCE, and Freon) and SVOCs (Phenol)	In design; Design completion planned '93	PRP Lead	Pattie Collins 415-744-2229 FTS 484-2229
9	Fairchild Semiconductor/MTV-II, CA* (06/30/89)	Vapor Extraction	Semiconductor Manufacturing Facility, Metal Finisher	Soil (quantity not available)	VOCs (TCE, PCE, Vinyl Chloride, DCA, DCE, and Freon) and SVOCs (Phenol)	Design completion planned '93	PRP Lead	Pattie Collins 415-744-2229 FTS 484-2229

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

Vacuum Extraction

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
9	IBM (San Jose), CA* (12/15/88) (site delisted 10/04/89)	Vapor Extraction	Computer Manufacturer	Soil (24,000 cy)	VOCs (Xylenes, Acetone, Freon, Isopropyl Alcohol, Petroleum Naphtha, and TCA)	Installation underway; will be operational in 1991	PRP Lead/ State Enforcement; Terra Vac	Helen McKinley 415-744-2236 FTS 484-2236 Will Bruhns (CA) 415-464-0838
9	Intel, Mountain View, CA* (06/09/89)	Vapor Extraction	Semiconductor Manufacturing Facility, Metal Finisher, Aircraft Maintenance	Soil (quantity not available)	VOCS (TCE, PCE, Vinyl Chloride, DCA, DCE, and Freon) and SVOCs (Phenol)	In design; Design completion planned '93	PRP Lead	Pattie Collins 415-744-2229 FTS 484-2229
9	Intersil/Siemens, CA (09/27/90)	Vapor Extraction	Semiconductor Manufacturer	Soil (quantity not available)	VOCs (total)	Operational	State Lead; Levine-Frisks	Marie Lacey 415-744-2234 FTS 484-2234
9	Raytheon, Mountain View, CA* (06/09/89)	Vapor Extraction	Semiconductor Manufacturing Facility, Metal Finisher, Aircraft Maintenance	Soil (quantity not available)	VOCs (TCE, PCE, Vinyl Chloride, DCA, DCE, and Freon) and SVOCs (Phenol)	In design; Design completion planned '93	PRP Lead	Pattie Collins 415-744-2229 FTS 484-2229
9	Solvent Service, CA* (09/27/90)	Vacuum Extraction (Heat enhanced SVE)	Solvent Operation	Soil (quantity not available)	VOCs (Total, Acetone, Ethylbenzene, TCA, and Xylenes), and SVOCs (Dichlorobenzene)	Operational	State Lead under RCRA Authority	Marie Lacey 415-744-2234 FTS 484-2234
9	Watkins-Johnson, CA* (06/29/90)	Vapor Extraction	Electronics Manufacturing	Soil (up to 20' depth - quantity not available)	VOCs (DCE, TCA, and TCE)	Predesign	PRP Lead	Elizabeth Keicher 415-744-2361 FTS 484-2361
10	Commencement Bay/S. Tacoma Channel/Well 12A WA (1987) (This site was inadvertently omitted from the tabulations used for the graphics in the introduction)	Soil aeration	Solvent Recycling	Soil (100,000 cy; to 35 ft deep)	VOCs (PCE, TCE, and TCA)	Contracted; installation to begin late October 1991	Fund lead AWD Technologies, Inc.	Kevin Rochlin 206-553-2106 FTS 399-2106

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

8.14 EXHIBIT 3 - INNOVATIVE TREATMENT TECHNOLOGIES: SEMI-ANNUAL STATUS REPORT (continued)

8.15 EXHIBIT 4 - VAPOR PRESSURE

Vapor Pressure for Typical VOCs (torr = mm of Hg @ 0°C)	
1,4-dichlorobenzene	1.0 torr
1,2-dichlorobenzene	1.5
1,3-dichlorobenzene	2.2
1,1,2,2-tetrachloroethane	6.16
o-xylene	6.6
m-xylene	8.3
dibromochloromethane	8.99
ethylbenzene	9.6
chlorobenzene	12.0
tetrachloroethylene	18.5
methyl isobutyl ketone	19.9
1,1,2-trichloroethane	23.0
toluene	28.4
1,2-dichloropropane	53.3
trichloroethylene	69.0
1,2-dichloroethane	78.9
benzene	95.2
methyl ethyl ketone	95.3
cyclohexane	96.9
carbon tetrachloride	120.0
1,1,1-trichloroethane	124.0
n-hexane	152.0
chloroform	197.0
cis-1,2-dichloroethylene	201.0
1,1-dichloroethane	227.0
vinyl chloride	298.0
trans-1,2-dichloroethylene	331.0
methylene chloride	435.0
1,1-dichloroethylene	600.0
trichlorofluoromethane	803.0
chloroethane	1010.0

Note: Although all of these compounds are volatile, Vacuum Extraction will work better for compounds with high vapor pressures (low on the table) than those with relatively low vapor pressures. Vacuum extraction has been selected at Superfund sites to remove contaminants with vapor pressure as low as 8.

United States Environmental Protection Agency	Office of Emergency and Remedial Response Washington, DC 20460	Office of Research and Development Cincinnati, OH 45268
Superfund	EPA/540/2-91/006	May 1991

EPA

Engineering Bulletin
In Situ Soil Vapor Extraction Treatment

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants as a principal element." The Engineering Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial scoping needs. Addenda will be issued periodically to update the original bulletins.

Abstract

Soil vapor extraction (SVE) is designed to physically remove volatile compounds, generally from the vadose or unsaturated zone. It is an in situ process employing vapor extraction wells alone or in combination with air injection wells. Vacuum blowers supply the motive force, inducing air flow through the soil matrix. The air strips the volatile compounds from the soil and carries them to the screened extraction well.

Air emissions from the systems are typically controlled by adsorption of the volatiles onto activated carbon, thermal destruction (incineration or catalytic oxidation), or condensation by refrigeration [1, p. 26].*

SVE is a developed technology that has been used in commercial operations for several years. It was the selected remedy for the first Record of Decision (ROD) to be signed under the Superfund Amendments and Reauthorization Act of 1986 (the Verona Well Field Superfund Site in Battle Creek, Michigan). SVE has been chosen as a component of the ROD at over 30 Superfund sites [2] [3] [4] [5] [6].

Site-specific treatability studies are the only means of documenting the applicability and performance of an SVE system. The EPA Contact indicated at the end of this bulletin can assist in the location of other contacts and sources of information necessary for such treatability studies.

The final determination of the lowest cost alternative will be more site-specific than process equipment dominated. This bulletin provides information on the technology applicability, the limitations of the technology, the technology description, the types of residuals produced, site requirements, the latest performance data, the status of the technology, and sources for further information.

Technology Applicability

In situ SVE has been demonstrated effective for removing volatile organic compounds (VOCs) from the vadose zone. The effective removal of a chemical at a particular site does not, however, guarantee an acceptable removal level at all sites. The technology is very site-specific. It must be applied only after the site has been characterized. In general, the process works best in well drained soils with low organic carbon content. However, the technology has been shown to work in finer, wetter soils (e.g., clays), but at much slower removal rates [7, p. 5].

The extent to which VOCs are dispersed in the soil—vertically and horizontally—is an important consideration in deciding whether SVE is preferable to other methods. Soil excavation and treatment may be more cost effective when only a few hundred cubic yards of near-surface soils have been contaminated. If volume is in excess of 500 cubic yards, if the spill has penetrated more than 20 or 30 feet, or the contamination has spread through an area of several hundred square feet at a particular depth, then excavation costs begin to exceed those associated with an SVE system [8] [9] [10, p. 6].

The depth to groundwater is also important. Groundwater level in some cases may be lowered to increase the volume of the unsaturated zone. The water infiltration rate can be

* [reference number, page number]

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Table 1
Effectiveness of SVE on General Contaminant Groups For Soil

	Contaminant Groups	Effectiveness Soil
Organic	Halogenated volatiles	■
	Halogenated semivolatiles	▼
	Nonhalogenated volatiles	■
	Nonhalogenated semivolatiles	■
	PCBs	❑
	Pesticides	❑
	Dioxins/Furans	❑
	Organic cyanides	❑
	Organic corrosives	❑
Inorganic	Volatile metals	❑
	Nonvolatile metals	❑
	Asbestos	❑
	Radioactive materials	❑
	Inorganic corrosives	❑
	Inorganic cyanides	❑
Reactive	Oxidizers	❑
	Reducers	▼

■ Demonstrated Effectiveness: Successful treatability test at some scale completed
▼ Potential Effectiveness: Expert opinion that technology will work
❑ No Expected Effectiveness: Expert opinion that technology will not work

controlled by placing an impermeable cap over the site. Soil heterogeneities influence air movement as well as the location of chemicals. The presence of heterogeneities may make it more difficult to position extraction and inlet wells. There generally will be significant differences in the air permeability of the various soil strata which will affect the optimum design of the SVE facility. The location of the contaminant on a property and the type and extent of development in the vicinity of the contamination may favor the installation of an SVE system. For example, if the contamination exists beneath a building or beneath an extensive utility trench network, SVE should be considered.

SVE can be used alone or in combination with other technologies to treat a site. SVE, in combination with groundwater pumping and air stripping, is necessary when contamination has reached an aquifer. When the contamination has not penetrated into the zone of saturation (i.e., below the water table), it is not necessary to install a groundwater pumping system. A vacuum extraction well will cause the water table to rise and will saturate the soil in the area of the contamination. Pumping is then required to draw the water table down and allow efficient vapor venting [11, p.169].

SVE may be used at sites not requiring complete remediation. For example, a site may contain VOCs and nonvolatile contaminants. A treatment requiring excavation might be selected for the nonvolatile contaminants. If the site required excavation in an enclosure to protect a nearby populace from VOC emissions, it would be cost effective to extract the volatiles from the soil before excavation. This would obviate the need for the enclosure. In this case it would be necessary to vent the soil for only a fraction of the time required for complete remediation.

Performance data presented in this bulletin should not be considered directly applicable to other Superfund sites. A number of variables such as the specific mix and distribution of contaminants affect system performance. A thorough characterization of the site and a well-designed and conducted treatability study are highly recommended.

The effectiveness of SVE on general contaminant groups for soils is shown in Table 1. Examples of constituents within contaminant groups are provided in the "Technology Screening Guide For Treatment of CERCLA Soils and Sludges" [12]. This table is based on the current available information or professional judgment where no information was available. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the treatment efficiencies achieved will be acceptable at other sites. For the ratings used in this table, demonstrated effectiveness means that, at some scale, treatability tests showed that the technology was effective for that particular contaminant and matrix. The ratings of potential effectiveness, or no expected effectiveness are both based upon expert judgment. Where potential effectiveness is indicated, the technology is believed capable of successfully treating the contaminant group in a particular matrix. When the technology is not applicable or will probably not work for a particular combination of contaminant group and matrix, a no-expected-effectiveness rating is given. Another source of general observations and average removal efficiencies for different treatability groups is contained in the Superfund Land Disposal Restrictions (LDR) Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions," (OSWER Directive 9347.3-06FS, July 1989) [13] and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions," (OSWER Directive 9347.3-07FS, December 1989) [14].

Limitations

Soils exhibiting low air permeability are more difficult to treat with in situ SVE. Soils with a high organic carbon content have a high sorption capacity for VOCs and are more difficult to remediate successfully with SVE. Low soil temperature lowers a contaminant's vapor pressure, making volatilization more difficult [11].

Sites that contain a high degree of soil heterogeneity will likely offer variable flow and desorption performance, which will make remediation difficult. However, proper design of the vacuum extraction system may overcome the problems of heterogeneity [7, p. 19] [15].

It would be difficult to remove soil contaminants with low vapor pressures and/or high water solubilities from a site. The lower limit of vapor pressure for effective removal of a compound is 1 mm Hg abs. Compounds with high water solubilities, such as acetone, may be removed with relative ease from arid soils. However, with normal soils (i.e., moisture content ranging from 10 percent to 20 percent), the likelihood of successful remediation drops significantly because the moisture in the soil acts as a sink for the soluble acetone.

Technology Description

Figure 1 is a general schematic of the in situ SVE process. After the contaminated area is defined, extraction wells (1) are installed. Extraction well placement is critical. Locations must be chosen to ensure adequate vapor flow through the contaminated zone while minimizing vapor flow through other zones [11, p. 170]. Wells are typically constructed of PVC pipe that is screened through the zone of contamination [11]. The screened pipe is placed in a permeable packing; the unscreened portion is sealed in a cement/bentonite grout to prevent a short-circuited air flow direct to the surface. Some SVE systems are installed with air injection wells. These wells may either passively take in atmospheric air or actively use forced air injection [9]. The system must be designed so that any air injected into the system does not result in the escape of VOCs to the atmosphere. Proper design of the system can also prevent offsite contamination from entering the area being extracted.

The physical dimensions of a particular site may modify SVE design. If the vadose zone depth is less than 10 feet and the area of the site is quite large, a horizontal piping system or trenches may be more economical than conventional wells.

An induced air flow draws contaminated vapors and entrained water from the extraction wells through headers—usually plastic piping—to a vapor-liquid separator (2). There, entrained water is separated and contained for subsequent treatment (4). The contaminant vapors are moved by a vacuum blower (3) to vapor treatment (5).

Vapors produced by the process are typically treated by carbon adsorption or thermal destruction. Other methods—such as condensation, biological degradation, and ultraviolet oxidation—have been applied, but only to a limited extent.

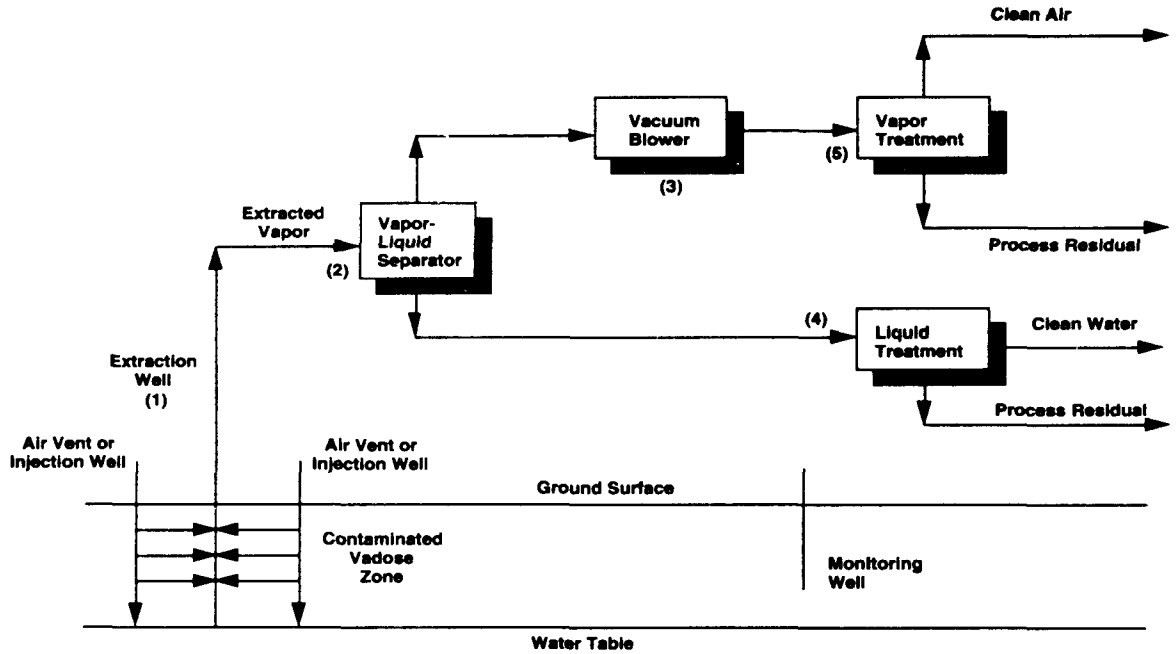
Process Residuals

The waste streams generated by in situ SVE are vapor and liquid treatment residuals (e.g., spent granular activated carbon [GAC]), contaminated groundwater, and soil tailings from drilling the wells. Contaminated groundwater may be treated and discharged onsite [12, p. 86] or collected and treated offsite. Highly contaminated soil tailings from drilling must be collected and may be either cleaned onsite or sent to an offsite, permitted facility for treatment by another technology such as incineration.

Site Requirements

SVE systems vary in size and complexity depending on the capacity of the system and the requirements for vapor and liquid treatment. They are typically transported by vehicles ranging from trucks to specifically adapted flatbed semitrailers; therefore, a proper staging area for these vehicles must be incorporated in the plans.

Figure 1
Process Schematic of the In Situ Soil Vapor Extraction System



Adequate access roads must be provided to bring mobile drilling rigs onsite for construction of wells and to deliver equipment required for the process (e.g., vacuum blowers, vapor-liquid separator, emission control devices, GAC canisters).

A small commercial-size SVE system would require about 1,000 square feet of ground area for the equipment. This area does not include space for the monitoring wells which might cover 500 square feet. Space may be needed for a forklift truck to exchange skid-mounted GAC canisters when regeneration is required. Large systems with integrated vapor and liquid treatment systems will need additional area based on vendor-specific requirements.

Standard 440V, three-phase electrical service is needed. For many SVE applications, water may be required at the site. The quantity of water needed is vendor- and site-specific.

Contaminated soils or other waste materials are hazardous, and their handling requires that a site safety plan be developed to provide for personnel protection and special handling measures. Storage should be provided to hold the process product streams until they have been tested to determine their acceptability for disposal or release. Depending upon the site, a method to store soil tailings from drilling operations may be necessary. Storage capacity will depend on waste volume.

Onsite analytical equipment, including gas chromatographs and organic vapor analyzers capable of determining site-specific organic compounds for performance assessment, make the operation more efficient and provide better information for process control.

Performance Data

SVE, as an in situ process (no excavation is involved), may require treatment of the soil to various cleanup levels mandated by federal and state site-specific criteria. The time required to meet a target cleanup level (or performance objective) may be estimated by using data obtained from bench-scale and pilot-scale tests in a time-predicting mathematical model. Mathematical models can estimate cleanup time to reach a target level, residual contaminant levels after a given period of operation and can predict location of hot spots through diagrams of contaminant distribution [16].

Table 2 shows the performance of typical SVE applications. It lists the site location and size, the contaminants and quantity of contaminants removed, the duration of operation, and the maximum soil contaminant concentrations before treatment and after treatment. The data presented for specific contaminant removal effectiveness were obtained, for the most part, from publications developed by the respective SVE system vendors. The quality of this information has not been determined.

Midwest Water Resources, Inc. (MWRI) installed its VAPORTECH™ pumping unit at the Dayton, Ohio site of a spill of uncombusted paint solvents caused by a fire in a paint warehouse [19]. The major VOC compounds identified were acetone, methyl isobutyl ketone (MIBK), methyl ethyl ketone (MEK), benzene, ethylbenzene, toluene, naphtha, xylene, and other volatile aliphatic and alkyl benzene compounds. The site is underlain predominantly by valley-fill glacial outwash within the Great Miami River Valley, reaching a thickness of over 200 feet. The outwash is composed chiefly of coarse, clean sand and gravel, with numerous cobbles and small boulders. There are two outwash units at the site separated by a discontinuous till at depths of 65 to 75 feet. The upper outwash forms an unconfined aquifer with saturation at a depth of 45 to 50 feet below grade. The till below serves as an aquitard between the upper unconfined aquifer and the lower confined to semiconfined aquifer. Vacuum withdrawal extended to the depth of groundwater at about 40 to 45 feet. During the first 73 days of operation, the system yielded 3,720 pounds of volatiles and after 56 weeks of operation, had recovered over 8,000 pounds of VOCs from the site. Closure levels for the site were developed for groundwater VOC levels of ketones only. These soil action levels (acetone, 810 µg/l; MIBK, 260 µg/l, and MEK, 450 µg/l) were set so that waters recharging through contaminated soils would result in

Table 2.
Summary of Performance Data for In Situ Soil Vapor Extraction

Site	*Size*	*Contaminants*	*Quantity removed*	*Duration of operation*	*Soil concentrations (mg/kg) max. before treatment*	*Soil concentrations (mg/kg) after treatment*
Industrial - CA [17]	--	TCE	30 kg	440 days	0.53	0.06
Sheet Metal Plant - MI [18]	5,000 cu yds	PCE*	59 kg	35 days	5600	0.70
Prison Const. Site - MI [19]	165,000 cu yds	TCA	--	90 days	3.7	0.01
Sherwin-Williams Site - OH [19]	425,000 cu yds	Paint solvents	4,100 kg	6 mo	38	0.04
Upjohn - PR [20][21]	7,000,000 cu yds	CCl_4	107,000 kg	3 yr	2200	<0.005
UST Bellview - FL [7]	--	BTEX	9,700 kg	7 mo	97	<0.006
Verona Wellfield - MI [7][22]	35,000 cu yds	TCE, PCE, TCA	12,700 kg	Over 1 yr	1380	Ongoing
Petroleum Terminal - Owensboro, KY [19]	12,000 cu yds	Gasoline, diesel	--	6 mo	>5000	1.0 (target)
SITE Program - Groveland MA [7]	6,000 cu yds	TCE	590 kg	56 days	96.1	4.19

*PCE = Perchloroethylene

groundwater VOC concentrations at or below regulatory standards. The site met all the closure criteria by June 1988.

A limited amount of performance data is available from Superfund sites. The EPA Superfund Innovative Technology Evaluation (SITE) Program's Groveland, Massachusetts, demonstration of the Terra Vac Corporation SVE process produced data that were subjected to quality assurance/quality control tests. These data appear in Table 2 [7, p. 29] and Table 3 [7, p. 31]. The site is contaminated by trichloroethylene (TCE), a degreasing compound which was used by a machine shop that is still in operation. The subsurface profile in the test area consists of medium sand and gravel just below the surface, underlain by finer and silty sands, a clay layer 3 to 7 feet in depth, and—below the clay layer—coarser sands with gravel. The clay layer or lens acts as a barrier against gross infiltration of VOCs into subsequent subsoil strata. Most of the subsurface contamination lay above the clay lens, with the highest concentrations adjacent to it. The SITE data represent the highest percentage of contaminant reduction from one of the four extraction wells installed for this demonstration test. The TCE concentration levels are weighted average soil concentrations obtained by averaging split spoon sample concentrations every 2 feet over the entire 24-foot extraction well depth. Table 3 shows the reduction of TCE in the soil strata near the same extraction well. The Groveland Superfund Site is in the process of being remediated using this technology [2].

The Upjohn facility in Barceloneta, Puerto Rico, is the first and, thus far, the only Superfund site to be remediated with SVE. The contaminant removed from this site was a mixture containing 65 percent carbon tetrachloride (CCl_4) and 35 percent acetonitrile [20]. Nearly 18,000 gallons of CCl_4 were extracted during the remediation, including 8,000 gallons that were extracted during a pilot operation conducted from January 1983 to April 1984. The volume of soil treated at the Upjohn site amounted to 7,000,000 cubic yards. The responsible party originally argued that the site should be considered clean when soil samples taken from four boreholes drilled in the area of high pretest contamination show nondetectable levels of CCl_4. EPA did not accept this criterion but instead required a cleanup criteria of nondetectable levels of CCl_4 in all the exhaust stacks for 3 consecutive months [21]. This requirement was met by the technology and the site was considered remediated by EPA.

Approximately 92,000 pounds of contaminants have been recovered from the Tyson's Dump site (Region 3) between November 1988 and July 1990. The site consists of two unlined lagoons and surrounding areas formerly used to store chemical wastes. The initial Remedial Investigation identified no soil heterogeneities and indicated that the water table was 20 feet below the surface. The maximum concentration in the soil (total VOCs) was approximately 4 percent. The occurence of dense nonaqueous-phase liquids (DNAPLs) was limited in areal extent. After over 18 months of operation, a number of difficulties have been encountered. Heterogeneities in soil grain size, water content, permeability, physical structure and compaction, and in contaminant concentrations have been identified. Soil contaminant concentrations of up to 20 percent and widespread distribution of DNAPLs have been found. A tar-like substance, which has caused plugging, has been found in most of the extraction wells. After 18 months of operation, wellhead concentrations of total VOCs have decreased by greater than 90 percent [23, p. 28].

As of December 31, 1990, approximately 45,000 pounds of VOCs had been removed from the Thomas Solvent Raymond Road Operable Unit at the Verona Well Field site (Region 5). A pilot-scale system was tested in the fall of 1987 and a full-scale operation began in March, 1988. The soil at the site consists of poorly-graded, fine-to-medium-grained loamy soils underlain by approximately 100 feet of sandstone. Groundwater is located 16 to 25 feet below the surface. Total VOC concentrations in the combined extraction well header have decreased from a high of 19,000 ug/1 in 1987 to approximately 1,500 ug/1 in 1990 [22].

Table 3
Extraction Well 4: TCE Reduction in Soil Strata—EPA Site Demonstration (Groveland, MA) [7, p. 31]

Depth (ft)	*Description of strata*	*Hydraulic Conductivity (cm/s)*	*Soil TCE concentration (mg/kg)* *Pre-treatment*	*Post-treatment*
0-2	Med. sand w/gravel	10^{-4}	2.94	ND
2-4	Lt. brown fine sand	10^{-4}	29.90	ND
4-6	Med. stiff lt. brown fine sand	10^{-5}	260.0	39.0
6-8	Soft dk. brown fine sand	10^{-5}	303.0	9.0
8-10	Med. stiff brown sand	10^{-4}	351.0	ND
10-12	V. stff lt. brown med. sand	10^{-4}	195.0	ND
12-14	V. Stiff brown fine sand w/silt	10^{-4}	3.14	2.3
14-16	M. stff grn-brn clay w/silt	10^{-8}	ND	ND
16-18	Soft wet clay	10^{-8}	ND	ND
18-20	Soft wet clay	10^{-8}	ND	ND
20-22	V. stiff brn med-coarse sand	10^{-4}	ND	ND
22-24	V. stiff brn med-coarse w/gravel	10^{-3}	6.17	ND

ND - Nondetectable level

An SVE pilot study has been completed at the Colorado Avenue Subsite of the Hastings (Nebraska) Groundwater Contamination site (Region 7). Trichloroethylene (TCE), 1,1,1-trichloroethane (TCA), and tetrachloroethylene (PCE) occur in two distinct unsaturated soil zones. The shallow zone, from the surface to a depth of 50 to 60 feet, consists of sandy and clayey silt. TCE concentrations as high as 3,600 ug/1 were reported by EPA in this soil zone. The deeper zone consists of interbedded sands, silty sands, and gravelly sands extending from about 50 feet to 120 feet. During the first 630 hours of the pilot study (completed October 11, 1989), removal of approximately 1,488 pounds of VOCs from a deep zone extraction well and approximately 127 pounds of VOCs from a shallow zone extraction well were reported. The data suggest that SVE is a viable remedial technology for both soil zones [24].

As of November, 1989, the SVE system at the Fairchild Semi-conductor Corporation's former San Jose site (Region 9) has reportedly removed over 14,000 pounds of volatile contaminants. Total contaminant mass removal rates for the SVE system fell below 10 pounds per day on October 5, 1989 and fell below 6 pounds per day in December, 1989. At that time, a proposal to terminate operation of the SVE system was submitted to the Regional Water Quality Control Board for the San Francisco Bay Region [25, p.3].

Resource Conservation and Recovery Act (RCRA) LDRs that require treatment of wastes to best demonstrated available technology (BDAT) levels prior to land disposal may sometimes be determined to be applicable or relevant and appropriate requirements for CERCLA response actions. SVE can produce a treated waste that meets treatment levels set by BDAT but may not reach these treatment levels in all cases. The ability to meet required treatment levels is dependent upon the specific waste constituents and the waste matrix. In cases where SVE does not meet these levels, it still may, in certain situations, be selected for use at the site if a treatability variance establishing alternative treatment levels is obtained. EPA has made the treatability variance process available in order to ensure that LDRs do not unnecessarily restrict use of alternative and innovative treatment technologies. Treatability variances are justified for handling complex soil and debris matrices. The following guides describe when and how to seek a treatability variance for soil and debris: Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions" (OSWER Directive 9347.3-06FS, July 1989) [13], and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-07FS, December 1989) [14]. Another approach could be to use other treatment techniques in series with SVE to obtain desired treatment levels.

Technology Status

During 1989, at least 17 RODs specified SVE as part of the remedial action [5]. Since 1982, SVE has been selected as the remedial action, either alone or in conjunction with other treatment technologies, in more than 30 RODs for Superfund sites [2] [3] [4] [5] [6]. Table 4 presents the location, primary contaminants, and status for these sites [3] [4] [5]. The technology also has been used to clean up numerous underground gasoline storage tank spills.

A number of variations of the SVE system have been investigated at Superfund sites. At the Tinkhams Garage Site in New Hampshire (Region 1), a pilot study indicated that SVE, when used in conjunction with ground water pumping (dual extraction), was capable of treating soils to the 1 ppm clean-up goal [26, 3-7] [27]. Soil dewatering studies have been conducted to determine the feasability of lowering the water table to permit the use of SVE at the Bendix, PA Site (Region 3) [28]. Plans are underway to remediate a stockpile of 700 cubic yards of excavated soil at the Sodeyco Site in Mt. Holly, NC using SVE [29].

With the exception of the Barceloneta site, no Superfund site has yet been cleaned up to the performance objective of the technology. The performance objective is a site-specific contaminant concentration, usually in soil. This objective may be calculated with mathematical models with which EPA evaluates delisting petitions for wastes contaminated with VOCs [30]. It also may be possible to use a TCLP test on the treated soil with a corresponding drinking water standard contaminant level on the leachate.

Most of the hardware components of SVE are available off the shelf and represent no significant problems of availability. The configuration, layout, operation, and design of the extraction and monitoring wells and process components are site specific. Modifications may also be required as dictated by actual operating conditions.

On-line availability of the full-scale systems described in this bulletin is not documented. System components are highly reliable and are capable of continuous operation for the duration of the cleanup. The system can be shut down, if necessary, so that component failure can be identified and replacemnts made quickly for minimal downtime.

Based on available data, SVE treatment estimates are typically $50/ton for treatment of soil. Costs range from as low as $10/ton to as much as $150/ton [7]. Capital costs for SVE consist of extraction and monitoring well construction; vacuum blowers (positive displacement or centrifugal); vapor and liquid treatment systems piping, valves, and fittings (usually plastic); and instrumentation [31]. Operations and maintenance costs include labor, power, maintenance, and monitoring activities. Offgas and collected groundwater treatment are the largest cost items in this list; the cost of a cleanup can double if both are treated with activated carbon. Electric power costs vary by location (i.e., local utility rates and site conditions). They may be as low as 1 percent or as high as 2 percent of the total project cost.

Caution is recommended in using these costs out of context, because the base year of the estimates vary. Costs also are highly variable due to site variations as well as soil and contaminant characteristics that impact the SVE process. As contaminant concentrations are reduced, the cost effectiveness of an SVE system may decrease with time.

Table 4
Superfund Sites Specifying SVE as a Remedial Action

Site	Location (Region)	Primary Contaminants	Status
Groveland Wells 1 & 2	Groveland, MA (1)	TCE	SITE demonstration complete [2][7] Full-scale Remediation in design
Kellogg-Deering Well Field	Norwalk, CT (1)	PCE, TCE, and BTX	Pre-design [3] [5] [6]
South Municipal Water Supply Well	Peterborough, NH (1)	PCE, TCE, Toluene	Pre-design completion expected in the fall of 1991 [3] [5][6]
Tinkham Garage	Londonderry, NH (1)	PCE, TCE	Pre-design pilot study completed [26] [27]
Wells G & H	Woburn, MA (1)	PCE, TCE	In design [3] [5]
FAA Technical Center	Atlantic County, NJ (2)	BTX, PAHs, Phenols	In design [3] [5]
Upjohn Manufacturing Co.	Barceloneta, PR (2)	CCl_4	Project completed in 1988 [20] [21]
Allied Signal Aerospace-Bendix Flight System Div.	South Montrose, PA (3)	TCE	Pre-design tests and dewatering study completed [28]
Henderson Road	Upper Merion Township, PA (3)	PCE, TCE, Toluene, Benzene	Pre-design [3] [4]
Tyson's Dump	Upper Merion Township, PA (3)	PCE, TCE, Toluene, Benzene, Trichloropropane	In operation (since 11/88) [23]
Stauffer Chemical	Cold Creek, AL (4)	CCL_4, pesticides	Pre-design [5] [6]
Stauffer Chemical	Lemoyne, AL (4)	CCL_4, pesticides	Pre-design [5] [6]
Sodyeco	Mt. Holly, NC (4)	TCE, PAHs	Design approved [29]
Kysor Industrial	Cadillac, MI (5)	PCE, TCE,Toluene, Xylene	In design; pilot studies in progress [3] [5] [6]
Long Prairie	Long Prairie, MN (5)	PCE, TCE, DCE, Vinyl chloride	SVE construction expected in the Fall of 1991 [3] [6]
MIDCO 1	Gary, IN (5)	BTX, TCE, Phenol, Dichloro-methane, 2-Butanone, Chlorobenzene	In Design [3] [5] [6]
Miami County Incinerator	Troy, OH (5)	PCE; TCE; Toluene	Pre-design [3] [5] [6]
Pristine	Cincinnati, OH (5)	Benzene; Chloroform; TCE; 1,2-DCA; 1,2-DCE	Pre-design [3] [6]
Seymour Recycling	Seymour, IN (5)	TCE; Toluene; Chloromethane; cis-1, 2-DCE; 1,1,1-DCA; Chloroform	Pre-design investigation completed [32]
Verona Well Field	Battle Creek, MI (5)	PCE, TCA	Operational since 3/81 [22]
Wausau Groundwater Contamination	Wausau, WI (5)	PCE, TCE	Pre-design [3] [5] [6]
South Valley/ General Electric	Albuquerque, NM (6)	Chlorinated solvents	Pilot studies scheduled for Summer of 1991 [4] [6]
Hastings Groundwater Contamination	Hastings, NE (7)	CCL_4 ,Chloroform	Pilot studies completed for Colorado Ave. & Far-Marco subsites [24]
Sand Creek Industrial	Commerce City, CO (8)	PCE, TCE, pesticides	Pilot study completed [33]
Fairchild Semiconductor	San Jose, CA (9)	PCE, TCA, DCE, DCA, Vinyl chlorides, Phenols, and Freon	Operational since 1988, Currently conducting resaturation studies [25]
Fairchild Semiconductor/ MTV-1	Mountain View, CA (9)	PCE, TCA, DCE, DCA, Vinyl chlorides, Phenols, and Freon	Pre-design [3] [5]
Fairchild Semiconductor/ MTV-2	Mountain View, CA (9)	PCE, TCA, DCE, DCA, Vinyl chlorides, Phenols, and Freon	Pre-design [3] [5]
Intel Corporation	Mountain View, CA (9)	PCE, TCA, DCE, DCA, Vinyl chlorides, Phenols, and Freon	Pre-design [3] [5]
Raytheon Corporation	Mountain View, CA (9)	PCE, TCA, DCE, DCA, Vinyl chlorides, Phenols, and Freon	Pre-design [3] [5]
Motorola 52nd Street	Phoenix, AZ (9)	TCA, TCE, CCL_4, Ethylbenzene	Pre-design [3] [4] [6]
Phoenix-Goodyear Airport Area (also Litchfield Airport Area)	Goodyear, AZ (9)	TCE, DCE, MEK	North Unit - In design [34] South Unit - pilot study completed

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TOXIC TREATMENTS (USA) INC.
(In-Situ Steam/Air Stripping)

TECHNOLOGY DESCRIPTION:

In this technology, a transportable "detoxifier" treatment unit is used for in-situ steam and air stripping of volatile organics from contaminated soil.

The two main components of the on-site treatment equipment are the process tower and process train (Figure 1). The process tower contains two counter-rotating hollow-stem drills, each with a modified cutting bit 5 feet in diameter, capable of operating to a 27-foot depth. Each drill contains two concentric pipes. The inner pipe is used to convey steam to the rotating cutting blades. The steam is supplied by an oil-fired boiler at 450°F and 450 psig. The outer pipe conveys air at approximately 300°F and 250 psig to the rotating blades.

Steam is piped to the top of the drills and injected through the cutting blades. The steam heats the ground being remediated, increasing the vapor pressure of the volatile contaminants and thereby increasing the rate at which they can be stripped. Both the air and steam serve as carriers to convey these contaminants to the surface. A metal box, called a shroud, seals the process area above the rotating cutter blades from the outside environment, collects the volatile contaminants, and ducts them to the process train.

In the process train, the volatile contaminants and the water vapor are removed from the off-gas stream by condensation. The condensed water is separated from the contaminants by distillation, then filtered through activated carbon beds and subsequently used as make-up water for a wet cooling tower. Steam is also used to regenerate the activated carbon beds and as the heat source for distilling the volatile contaminants from the condensed liquid stream. The recovered concentrated organic liquid can be recycled or used as a fuel in an incinerator.

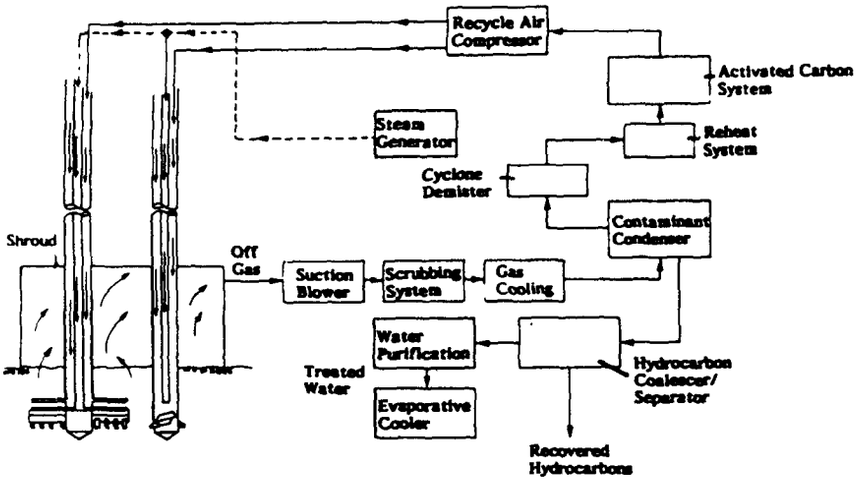

Figure 1. Typical detoxifer system process flow diagram.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

This technology is applicable to organic contaminants such as hydrocarbons and solvents with sufficient vapor pressure in the soil. The technology is not limited by soil particle size, initial porosity, chemical concentration, or viscosity.

STATUS:

A SITE demonstration was performed the week of September 18, 1989 at the Annex Terminal, San Pedro, CA. Twelve soil blocks were treated for VOCs and SVOCs. Various liquid samples were collected from the process during operation, and the process operating procedures were closely monitored and recorded. Post-treatment soil samples were collected and analyzed by EPA 8240 and 8270. In January 1990, 6 blocks which had been previously treated in the saturated zone were analyzed for EPA 8240 and 8270 chemicals. Currently, the Technology Evaluation Report has obtained EPA clearance for publication. The Application Analysis Report is being prepared.

DEMONSTRATION RESULTS:

The following results were obtained during the SITE demonstration of the technology:

- Greater than 85 percent of the VOCs in the soil were removed.
- As much as 55 percent of SVOCs in the soil were removed.
- Fugitive air emissions from the process were very low.
- No downward migration of contaminants occurred due to the soil treatment.

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SITE Technology Profile

DEMONSTRATION PROGRAM

AWD TECHNOLOGIES, INC.
(Integrated Vapor Extraction and Steam Vacuum Stripping)

TECHNOLOGY DESCRIPTION:

The integrated AquaDetox/SVE system simultaneously treats ground water and soil contaminated with volatile organic compounds (VOCs). The integrated system consists of two basic processes: an AquaDetox moderate vacuum stripping tower that uses low-pressure steam to treat contaminated ground water; and a soil gas vapor extraction/reinjection (SVE) process to treat contaminated soil. The two processes form a closed-loop system that provides simultaneous in-situ remediation of contaminated ground water and soil with no air emissions.

AquaDetox is a high efficiency, countercurrent stripping technology developed by Dow Chemical Company. A single-stage unit will typically reduce up to 99.99 percent of VOCs from water. The SVE system uses a vacuum to treat a VOC-contaminated soil mass, inducing a flow of air through the soil and removing vapor phase VOCs with the extracted soil gas. The soil gas is then treated by carbon beds to remove additional VOCs and reinjected into the ground. The AquaDetox and SVE system (Figure 1) share a granulated activated carbon (GAC) unit. Noncondensable vapor from the AquaDetox system is combined with the vapor from the SVE compressor and decontaminated by the GAC unit. By-products of the system are a free-phase recyclable product and treated water. Mineral regenerable carbon will require disposal after approximately three years.

A key component of the closed-loop system is a vent header unit designed to collect the noncondensable gases extracted from the ground water or air that may leak into the portion of the process operating below atmospheric pressure. Further, the steam used to regenerate the carbon beds is condensed and treated in the AquaDetox system.

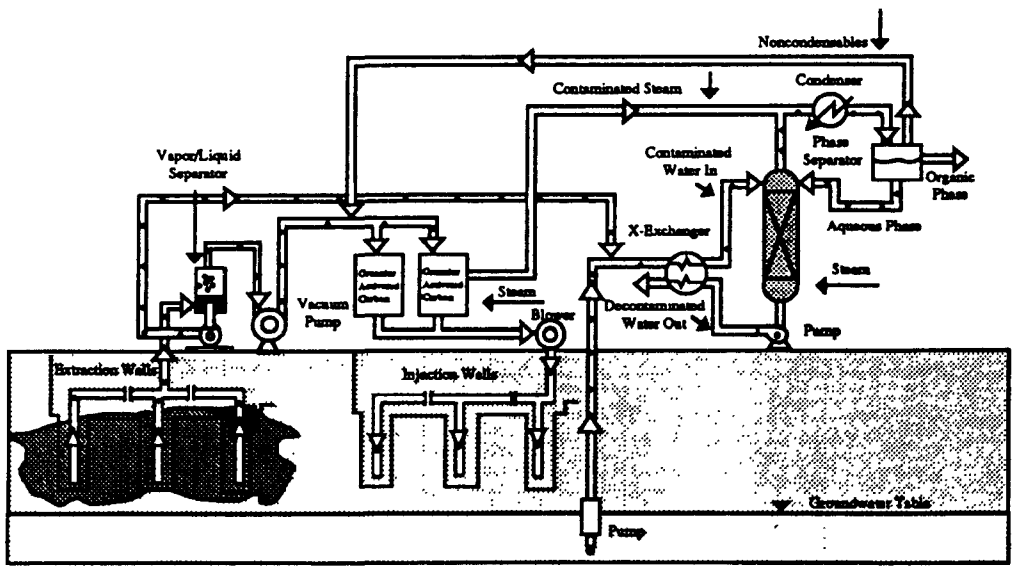

Figure 1. Zero air emissions integrated AquaDetox/SVE system.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

This technology removes VOCs, including chlorinated hydrocarbons, in ground water and soil. Sites with contaminated ground water and soils containing trichloroethylene (TCE), perchloroethylene (PCE), and other VOCs are suitable for this on-site treatment process. AquaDetox is capable of effectively removing over 90 of the 110 volatile compounds listed in 40 CFR Part 261, Appendix VIII.

STATUS:

The AWD AquaDetox/SVE system is currently being used at the Lockheed Aeronautical Systems Company in Burbank, California. At this site, the system is treating ground water contaminated with as much as 2,200 ppb of TCE and 11,000 ppb PCE; and soil gas with a total VOC concentration of 6,000 ppm. Contaminated ground water is being treated at a rate of up to 1,200 gpm while soil gas is removed and treated at a rate of 300 cfm. The system occupies approximately 4,000 square feet.

A SITE demonstration project was evaluated as part of the ongoing remediation effort at the San Fernanco Valley Ground-Water Basin Superfund site in Burbank, California. Demonstration testing was conducted in September 1990. Demonstration results are currently being prepared and are expected to be published in early 1991.

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SITE Technology Profile

DEMONSTRATION PROGRAM

TERRA VAC, INC.
(In-Situ Vacuum Extraction)

TECHNOLOGY DESCRIPTION:

In-situ vacuum extraction technology is the process of removing and treating volatile organic compounds (VOCs) from the vadose or unsaturated zone of soils. Often, these compounds can be removed from the vadose zone before they contaminate ground water. In this technology, a well is used to extract subsurface organic contaminants. The extracted contaminant stream passes through a vapor/liquid separator, and the resulting off-gases undergo treatment, before being released into the atmosphere. Removing VOCs from the vadose zone using a vacuum is a patented process.

The technology uses readily available equipment such as extraction and monitoring wells, manifold piping, a vapor/liquid separator, a vacuum pump, and an emission control device, such as an activated carbon canister. Once a contaminated area is completely defined, an extraction well is installed and connected by piping to a vapor/liquid separator device.

A vacuum pump draws the subsurface contaminants through the well, to the separator device, and through a treatment system consisting of activated carbon or a catalytic oxidizer before the air stream is discharged to the atmosphere. Subsurface vacuum and soil vapor concentrations are monitored using vadose zone monitoring wells.

The technology does not require soil excavation, and is not limited by depth. The technology works best at sites that are contaminated by liquids with high vapor pressures. The success of the system depends on site conditions, soil properties, and the chemical properties of the contaminants. The process works in soils of low permeability (clays) if the soil has sufficient air-filled porosity. Depending on the soil type and the depth to ground water, the radius of influence of a single extraction well can range from tens to hundreds of feet.

Typical contaminant recovery rates range between 20 and 2,500 pounds per day, and are a function of the degree of contamination at the site. Typically the more volatile the organic compound, the faster the process works. The process is cost-effective at sites where contaminated soils are predominantly above or below the water table; dual vacuum extraction systems have been designed for both vapor and ground-water recovery (Figure 1).

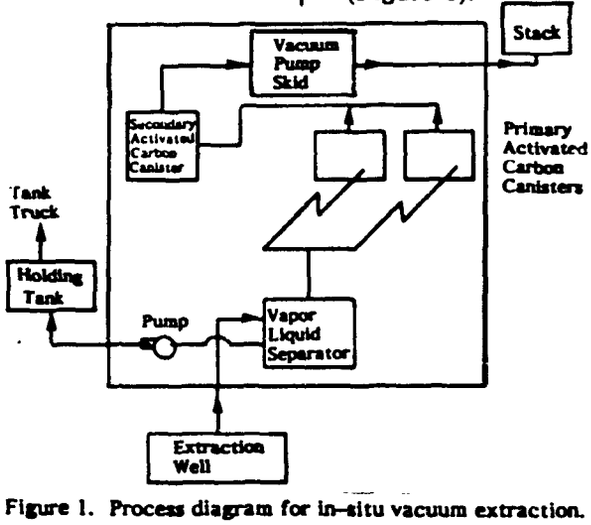

Figure 1. Process diagram for in-situ vacuum extraction.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

This technology is applicable to organic compounds that are volatile or semivolatile at ambient temperatures in soils and ground water. Contaminants should have a Henry's constant of 0.001 or higher for effective removal.

STATUS:

The technology was first applied at a Superfund site in Puerto Rico, where carbon tetrachloride had leaked from an underground storage tank. In-situ vacuum extraction processes have been used at more than 100 waste sites across the United States, such as the Verona Wells Superfund Site in Battle Creek, Michigan, which contains trichloroethylene and contaminants from solvent storage and spills. A field demonstration of the process was performed as part of the SITE Program at the Groveland Wells Superfund site in Groveland, Massachusetts, which is contaminated by trichloroethylene (TCE).

The Technology Evaluation Report and Applications Analysis Report have been published.

DEMONSTRATION RESULTS:

The in situ vacuum extraction demonstration at Groveland Wells Superfund site used four extraction wells to pump contaminants to the process system. Four monitoring wells were used to measure the impact of treatment on site contamination. During the SITE demonstration, 1,300 pounds of volatile organics, mainly TCE, were extracted during a 56-day operational period. The volatiles were removed from both highly permeable strata and low permeability clays. The process achieved nondetectable levels of VOCs in the soil at some locations at the test area. The VOC concentration in soil gas was reduced 95 percent.

APPLICATIONS ANALYSIS SUMMARY:

The Terra Vac system was tested at several Superfund and non-Superfund sites. These field evaluations yielded the following conclusions:

- The process represents a viable technology to fully remediate a site contaminated with volatile organic compounds. Cleanup to non-detectable levels in soil can be achieved.
- The major considerations in applying this technology are: volatility of the contaminants (Henry's constant), and the site soil porosity.
- The process performed well in removing volatile organic compounds from soil with measured permeabilities of 10^{-4} to 10^{-8} cm/sec.
- Pilot demonstrations are necessary at sites with complex geology or contaminant distributions.
- Based on available data, treatment costs are typically $40 per ton, but can range between $10 and $150 per ton depending upon requirements for off-gas or wastewater treatment.

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AIR FORCE ENGINEERING AND SERVICES CENTER

TECHDATA

IN SITU SOIL DECONTAMINATION BY RADIO-FREQUENCY HEATING

RDV 90-1 **November 90**

SYNOPSIS:

This technology can be applied to cleanup of soils contaminated by volatile and semivolatile petroleum and solvents.

Radio-frequency heating is performed by applying electromagnetic energy to the radio-frequency band. The energy is delivered by electrodes placed in holes drilled through the soil. The mechanism of heat generation is similar to that of a microwave oven and does not rely on the thermal properties of the soil matrix.

The power source for the process is a modified radio transmitter. The exact frequency of operation is selected after evaluation of the dielectric properties of the soil matrix and the size of the area requiring treatment.

The gases and vapors formed in the soil matrix can be recovered at the surface or through the electrodes used for the heating process. Condensation and collection of the concentrated vapor stream are used to capture the contaminant above ground.

A field test was performed at the Volk Field Air National Guard Base, Camp Douglas, Wisc. The field test revealed that 94 to 99 percent decontamination of a 500 ft^3 block of soil was achieved during a 12-day treatment period.

The block of soil, measuring 6 feet by 12 feet by 7 feet, was heated to a temperature range of 150 to 160 degrees Celsius. Analysis of numerous pre- and posttest soil samples has indicated that, on the average, 99 percent of the volatile aromatics and aliphatics had been removed from the 500-cubic foot heated volume; 94 percent of semivolatile aliphatics and 99 percent of the semivolatile aromatics were also removed.

Removal of higher boiling point contaminants also occurs from the steam distillation provided by native moisture. The soils at Volk Field are predominantly fine to coarse-grained sandstone with interbedded shale and overlying unconsolidated sand. Soils beneath the fire training area are 95 percent sand with 5 percent by weight finer than sand. Mineralogically, soils are at least 98 percent alpha quartz with no clay as determined by X-ray diffraction.

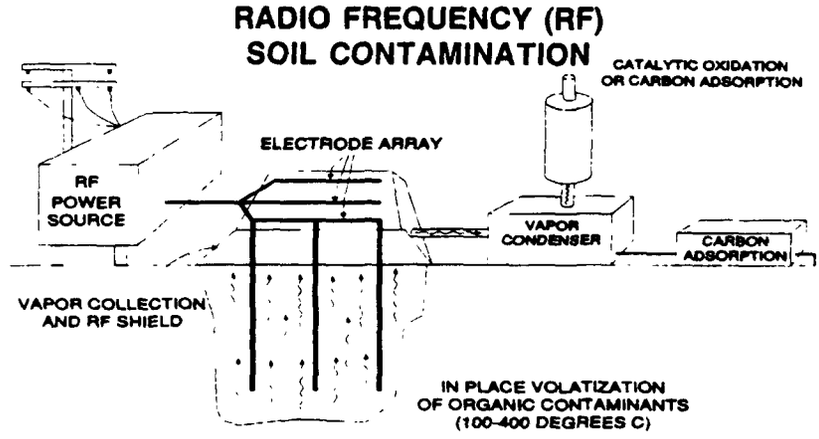

Diagram of RF soil venting.

Cost estimates for the full-scale system for the treatment of soil range from $29 to $60 per ton of contaminated soil.

APPLICATIONS:

Although the first field test proved promising, the process has not been tested at the full-scale level to assure even distribution of heat over a wide area (treating successive modules of 9200 square feet).

RF heating also has not been demonstrated in clay type soils. Both of these areas will be tested in a study in FY 91.

The process minimizes subsurface impact reducing fugitive vapors associated with excavation processes.

BENEFITS:

When developed and approved, this technology can provide a more cost-effective and efficient tool for removing hazardous chemicals from in situ soils and lead to better site remediation.

AVAILABILITY:

The first phase has proven successful for sandy soil in laboratory and scaled down field testing. Plans are underway to conduct full-scale testing at Kelly AFB. When testing is completed and approved, this method will be available.

DOCUMENTATION:

This technology is documented in ESL TR 88-62, *In Situ Soil Decontamination by Radio-Frequency Heating-Field Test*, published September, 1989.

TECHNICAL CONTACT:

Capt. Ed Marchand, HQ AFESC/RDVW, Tyndall AFB FL, 32403-6001, DSN 523-6023

E&S TechData sheets are products of HQ AFESC/RDXI, Tyndall AFB FL, 32403-6001.

United States Environmental Protection Agency | Risk Reduction Engineering Engineering Laboratory Cincinnati OH 45268
Research and Development | EPA/540/S2-91/003 June 1991

EPA **Project Summary**

Soil Vapor Extraction Technology Reference Handbook

Tom A. Pedersen and James T. Curtis

Soil vapor extraction (SVE) systems are being used in increasing numbers because of the many advantages these systems hold over other soil treatment technologies. SVE systems appear to be simple in design and operation, yet the fundamentals governing subsurface vapor transport are quite complex.

In view of this complexity, an expert workshop was held to discuss the state of the art of the technology, the best approach to optimize system application, and the process efficiency and limitations. As a result of the workshop, an SVE Technology Assessment report was produced. This report discusses the basic science of the subsurface environment and subsurface vapor flow, site investigations, SVE system design and operation, and includes selected papers from the expert workshop. Additional research activities being conducted include a field demonstration of a structured SVE system design approach, a laboratory column study to determine and characterize residuals following vapor extraction, an assessment of secondary emissions and regulations governing releases from SVE systems, cost of SVE implementation and operation, and a survey of techniques to enhance vapor removal.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

SVE is being used with increasing frequency throughout the country for the remediation of unsaturated zone soils that have become contaminated with volatile organics. SVE, also known as vacuum extraction, *in situ* vaporization, or soil venting, has many positive features that gives it an advantage over other soil treatment techniques such as excavation and offsite treatment, soil flushing, or biotreatment. Some of the features that make this technology applicable to a broad spectrum of sites are:

- SVE is an *in situ* technology, so there is a minimum of site disturbance; often, business operations at the site need not be interrupted;
- SVE can treat large volumes of soil at reasonable costs;
- SVE is easily installed and uses standard, readily-available equipment, which allows for rapid mobilization and implementation of remedial activities;
- SVE is effective in reducing the concentration of volatile organic compounds (VOCs) in the vadose zone, reducing the potential for further migration; and
- SVE complements groundwater pump and treat techniques, which may be instituted concurrently.

These features, combined with the apparent simplicity of SVE system design, implementation, and operation, have combined to make SVE one of the fastest growing remediation choices. This growth has not necessarily been accompanied by

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a broader expansion of the knowledge base to properly design and operate an SVE system. Indeed, the ease with which SVE systems can be installed and operated belies the very complex nature of subsurface vapor behavior and transport.

Much of the technical information regarding the design, construction, and operation of an extraction system is held by the SVE technology developers and vendors. Engineering practices, which are often considered proprietary by the developers may be based in large part on each developer's experiences. This atmosphere does not encourage rigorous objective review of design or operating methods and makes it more difficult to analyze the results of SVE use. This lack of knowledge poses limitations to regulatory agency personnel and others attempting to interpret system operating results.

The increased use of SVE systems and the need for a greater understanding of the principles that underlie soil vapor behavior and other issues related to SVE led the U.S. Environmental Protection Agency's Office of Research and Development, through its Risk Reduction Engineering Laboratory, Releases Control Branch (RREL-RCB) to initiate SVE research efforts. The initial step in these efforts was the convening of an expert workshop in Edison, NJ, on June 28 and 29, 1989. Workshop participants included SVE technology vendors, petroleum industry representatives, university researchers, consulting engineers, regulatory agency representatives, and others who were familiar with this technology. The workshop had dual objectives. One was to discuss the state of the art of SVE-related topics, such as: site characterization, pilot systems, full scale system design and operation, vapor treatment options, establishing and attaining cleanup goals, and monitoring SVE treatment progress. Some presenters discussed actual case studies; and others discussed a structured framework for conducting site investigations and system design, the use of modeling to help design extraction systems, and other research on SVE currently in progress. The second objective of the workshop was to discuss additional research needs. Panel discussions were held with workshop attendees regarding areas for future research and topics needing immediate attention. The regulatory climate was also discussed, including suggested remediation standards and methods to determine cleanup attainment. As a result of this workshop, an SVE Technology Reference Handbook was developed.

Reference Handbook

The main text of this document is an assessment of the state of the art of soil vapor extraction technology. It was written specifically for state and local regulators, agency staff, environmental managers, remedial contractors and consultants who desire a basic understanding of SVE principles, applicability, operation, and cost.

A general overview of the theoretical considerations applicable to soil vapor extraction is provided in Section 2. This section includes discussions of the effect on SVE of contaminant properties, including vapor pressure, solubility, Henry's law constant, boiling point, soil sorption coefficient, contaminant composition and weathering, and soil properties such as structure, moisture content, texture, air permeability, and temperature. Section 2 also discusses gaseous flow in the subsurface environment, including the equations that govern subsurface vapor flow. Finally, several field methods of determining the soil's air permeability are presented.

Section 3 provides an overview of site investigation approaches that can be used to obtain data necessary to determine if vapor extraction is a viable remedial option and, if so, obtain critical design information. This section also includes references to field techniques and equipment used to evaluate the site-specific feasibility of vapor extraction.

General design approaches, including the determination of the air permeability, well selection, and system configuration, are described in Section 4. In addition, this section discusses the components that comprise an SVE system. The purpose of this section is to provide the reader with a qualitative analysis of the design procedure and the individual components to aid in the preliminary design of such a system.

Operation, maintenance, and monitoring of SVE systems are discussed in Section 5. This section also includes discussions of enhanced biotreatment due to SVE; cleanup attainment determination, including new methods for measuring residuals; and other issues related to system operation.

Section 6 discusses emission control methods available to treat the extracted vapors. Discussions are included on activated carbon adsorption, thermal and catalytic incineration, internal combustion engines, packed bed thermal processors, biotreatment, and direct discharge to the atmosphere.

The costs related to SVE implementation and operation are discussed in Section 7. This section discusses costs for a site investigation, component-by-component capital costs for SVE equipment, costs for prepackaged units, and operations and monitoring costs for these systems.

Ten appendices contain selected papers presented at the Edison, NJ, workshop. Papers reprinted here were selected as representative of the wide range of topics discussed. Appendix A is a review of existing SVE operations by N.E. Hutzler, B.E. Murphy, and J.S. Gierke. This section reports on various aspects of SVE operations, including number, type, and layout of wells, type of blower or pump used, emission control units, and additional operational information. The section provides the reader with a sound historical basis with which to view other sections.

In Appendix B, J. Danko discusses the applicability and limitations of SVE operation. This paper describes the advantages of SVE and discusses, from an engineering viewpoint, some practical observations and advice.

Appendix C contains a report by H.B. Kerfoot on the use of soil gas surveys in the design of SVE systems. Soil gas surveys are frequently used during the site investigation phase to help delineate the extent of contamination and determine the types and relative concentrations of compounds in the ground. With this information, a judgment can often be rendered regarding the applicability of SVE for that site.

Appendix D, by R.E. Hinchee, D.C. Downey, and R.N. Miller, discusses the enhancement of biodegradation that accompanies the use of soil vapor extraction.

P.C. Johnson, M.W. Kemblowski, J.D. Colthart, D.L. Byers, and C.C. Stanley contribute "A Practical Approach to the Design, Operation, and Monitoring of *In Situ* Soil Venting Systems" in Appendix E. This report presents a structured logical approach that forms a "decision-tree" for deciding if SVE is appropriate to be used and, if so, describes the steps to be taken during system design, operation, and monitoring.

Appendix F contains a scientific approach to SVE design in a paper by M.C. Marley, S.D. Richter, B.L. Cliff, and P.E. Nangeroni. This paper describes, among other things, the use of a computer model to calibrate data obtained during a field air permeability test.

L.R. Silka, H.D. Cirpili, and D.C. Jordan discuss in Appendix G modeling of subsurface vapor flow and the applications of modeling to SVE.

D.W. DePaoli, S.E. Herbes, and M.G. Elliot describe in Appendix H the performance of SVE at a jet fuel spill site in Utah. This paper contains knowledge and experience gained during SVE operation,

operational results, and a discussion of various aspects of SVE.

Appendix I contains actual case history results for an industrial site that has contamination from several volatile organic and base neutral compounds in a report by R.D. Mutch, Jr., A.N. Clarke, D.J. Wilson, and P.D. Mutch. This interim report focuses on the measured zone of influence of the extraction well, the composition of the extracted gas and its changes with time, the treatability of the extracted vapor by granular activated carbon, temperature variations that occur in the system, and groundwater upwelling due to the induced vacuum. The authors also describe the use of a mathematical model in their work.

A report by G.E. Hoag in Appendix J comments on recent SVE research developments and research needs. These discussions follow a summary of SVE "research milestones."

Appendices K and L contain responses to a state-by-state survey conducted in August 1989 regarding the allowable soil residual and air discharge criteria.

This book is not intended for use as a design manual, but it documents all of the latest state of the art of the soil vapor extraction technology.

The full report was submitted in fulfillment of Contract No. 68-03-3409 by CDM Federal Programs Corporation under the sponsorship of the U.S. Environmental Protection Agency.

8.22 KEY REFERENCE LIST - VACUUM EXTRACTION

Danko, J., "Soil Vapor Extraction Applicability and Limitations," Proc. HazMat West 89, California, Long Beach, CA, pp. 537 - 544, Hazardous Materials Control Research Institute, Silver Spring, MD, 1989.

DePaoli, D.W., Herbes, S.E., and Elliott, M.G., Performance of In-Situ Soil Venting System at Jet Fuel Spill Site. Presented at U.S. EPA Soil Vapor Extraction Workshop, Edison, NJ, June 1989.

Downey, D.C., and Elliott, M.G., Performance of Selected In-Situ Soil Decontamination Technologies: A Summary of Two AFESC Field Tests. Presented at the American Institute of Chemical Engineers, Philadelphia, PA, August 1989.

Hutzler, N.J., et. al., State of Technology Review: Soil Vapor Extraction Systems. EPA 600/52-89/024. U.S. Environmental Protection Agency, Cincinnati, OH, January, 1990.

Hutzler, N.J., et. al., "Review of Soil Vapor Extraction System Technology," Proc. HazMat West '89, California, Long Beach, CA, pp. 512 - 536, Hazardous Materials Control Research Institute, Silver Spring, MD, 1989.

Malot, J., Vacuum Extraction of VOC Contamination in Soils. Dorado, Puerto Rico: Terra Vac, Inc., 1985.

Miller, Ross N., A Field Scale Investigation of Enhanced Petroleum Hydrocarbon Biodegradation in the Vadose Zone at Tyndall AFB, Florida, 1990.

U.S. Environmental Protection Agency, 1989. Applications Analysis Report - Terra Vac In-Situ Vacuum Extraction System, Groveland, MA, EPA 540/A5-89/003, (also in videocassette from EPA, Edison, NJ.)

U.S. Environmental Protection Agency, 1990. Handbook of In-situ Treatment of Hazardous Waste-Contaminated Soils. EPA/540/2-90/002, (Available from Risk Reduction Engineering Laboratory, Cincinnati, OH.)

U.S. Environmental Protection Agency, 1990. Inventory of Treatability Study Vendors, Volume 1, EPA/540/2-90/003a.

U.S. Environmental Protection Agency, 1990. Second Forum on Innovative Treatment Technologies, Domestic and International, Philadelphia, PA, May 15-17, 1990, EPA/540/2-90/006 (Abstracts) or EPA/540/2-90/010 (Technical Papers).

U.S. Environmental Protection Agency, 1989. State of Technology Review; Soil Vapor Extraction Systems, EPA/600/2-89/024.

U.S. Environmental Protection Agency, 1991. Soil Vapor Extraction Technology, Reference Handbook. EPA/5401/2-91/003 (Fact Sheet included).

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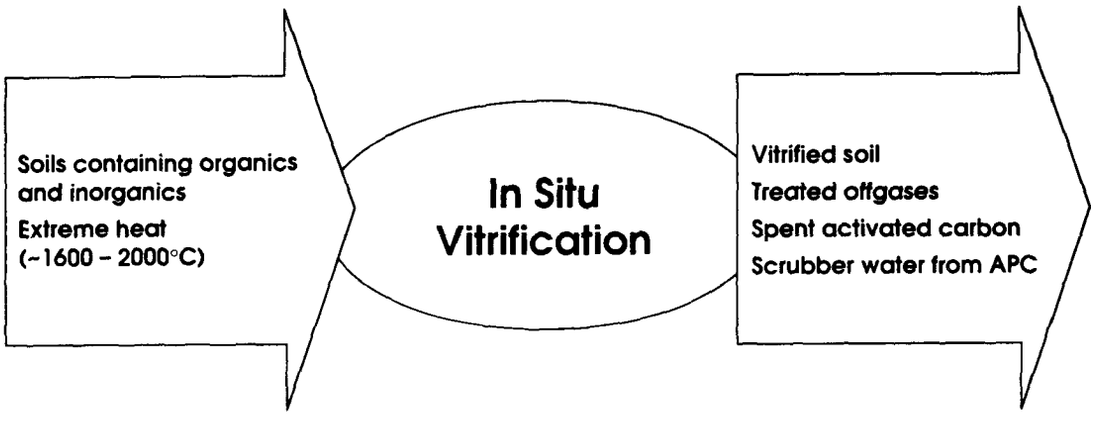
9.0 IN SITU VITRIFICATION

9.1 TECHNOLOGY DESCRIPTION

In situ vitrification (ISV) uses electrical power to heat and melt contaminated soils and sludges to form a stable glass and crystalline structure with very low leaching characteristics. ISV uses a square array of four electrodes inserted into the ground to establish a current in the soil, and heat the soil to a range of 2900° to 3600°F (1600 to 2000°C), well above a typical soil's melting point. As the melt is generated downward from the surface, organic contaminants are destroyed by pyrolysis and the pyrolized products migrate to the surfaces of the vitrified zone, where they combust in the presence of oxygen. Non-volatile inorganic contaminants are dissolved and incorporated into the melt. The resulting product is devoid of residual organics. A vacuum hood placed over the area collects off gases, which are treated before being released into the atmosphere.



9.2 TECHNOLOGY STATUS

- To date, engineering, pilot-scale, and full-scale tests have been conducted on in situ vitrification of hazardous wastes.
- This technology will treat 3,000 yd^3 of soils contaminated with pesticides as part of the Superfund removal action at the Parsons Chemical site, Grand Lodges, MI. In situ vitrification was selected after a successful treatability test. (The OSC for the project is Leonard Zintak, Jr., US EPA, Region V).
- A large-scale test has been conducted at Hanford, Washington, on mixed radioactive and chemical wastes containing chromium.
- Nine full scale tests have been performed at DOE sites.
- Only one vendor is licensed by the U.S. Department of Energy to perform ISV.
- ISV has been selected for evaluation under the SITE program.
- Three EPA regions have selected ISV to treat contaminated soils at Superfund sites contaminated with PCBs, heavy metals, organics, pesticides, and low-level dioxins. Exhibit 3 describes these sites.

9.3 APPLICATION

- In situ vitrification may be used to destroy, remove, or immobilize all contaminant groups - radioactive, organic, and inorganic. This technology is also appropriate for mixtures of wastes.
- The technology may be applied to most soil types. The two limiting factors are: (1) moisture content (excessive moisture must be driven off before vitrification, increasing costs significantly) and (2) presence of glass-forming materials (i.e., silicon and aluminum oxides). If the soil is too wet, it may be dewatered, and if there is insufficient glass-forming material, a fluxing material may be added.

9.4 TECHNOLOGY STRENGTHS

- Successfully tested for the treatment of radioactive and hazardous wastes.
- Produces a stable crystalline structure with long-term durability, encapsulating the residual inorganic waste.

9.5 TECHNOLOGY LIMITATIONS

- Requires off-gas collection and treatment and disposal of spent activated carbon, scrubber water, and other waste materials from the air pollution control equipment that may be hazardous.
- May require backfilling with clean soil since volume can decrease 20 to 40 percent.
- Because contaminants may migrate from the wastes at the periphery of the melt (side migration), a vitrification project may need to include clean material at the edges of the contaminated area to capture migrating contaminants. This will increase the cost of the project by increasing the quantity of material to be vitrified.
- Existing metallic pipes and scrap metals may cause substantial problems in full scale implementation.
- To effectively immobilize metals and radionuclides, adequate concentrations of glass-forming elements are required to ensure chemical durability of the product.
- ISV is not effective below the water table if the hydraulic conductivity is greater than 10^{-4}.
- The concentration of organic material in the waste must be less than 10% by weight to be accommodated with the existing off gas equipment.

9.6 POTENTIAL MATERIALS HANDLING REQUIREMENTS

- This technology is used in situ; no excavation is required. Some excavation and placement of wastes may be done to stage the waste and lower the cost of the project.
- The contaminated material may be dewatered if the ground water conditions at the site are such that dewatering is cost effective. Because this technology is more efficient with unsaturated soils, costs can be lowered by dewatering saturated or very wet areas before treatment. Because this is an in situ technology, the material must be dewatered with in situ methods such as well points and drains.

9.7 WASTE CHARACTERISTICS AFFECTING PERFORMANCE

- Soil moisture, which must be driven off before melting occurs, can have a major effect on cost.
- A second major factor affecting cost-effectiveness is the cost of electricity.
- The capability of the system depends on two factors: (1) the capabilities of the power supply and (2) the capacity of the off-gas system.

- The two factors that affect the ability of the power supply system are the presence of saline ground water and buried metals. Vitrification can take place in saturated soils with low permeabilities if the melting rate is greater than the rate of recharge.

- Miscellaneous buried metal, such as drums, should have little or no effect on the ability to process a site. A conduction path that could lead to shorting between electrodes should be avoided.

- The bulk chemistry of the waste material effects the melt temperature, viscosity of the melt, and durability of vitrified mass.

- The off-gas system should maintain a negative pressure to prevent any release of contamination. The concern is with the release of gas from relatively short transient events such as the release of entrapped air from intrusions into void spaces, penetration of a drum containing combustible material, and intrusion into areas containing solid or liquid combustible materials.

- Treatability tests should focus on performance requirements for the off-gas treatment system and the type and quantity of secondary waste generated. Almost all soils can be vitrified and this is generally not a serious consideration during treatability testing.

9.8 EXHIBIT 1 - WASTE CHARACTERISTIC TABLE

Waste Type: Soils and Sludges
Technology: In Situ Vitrification

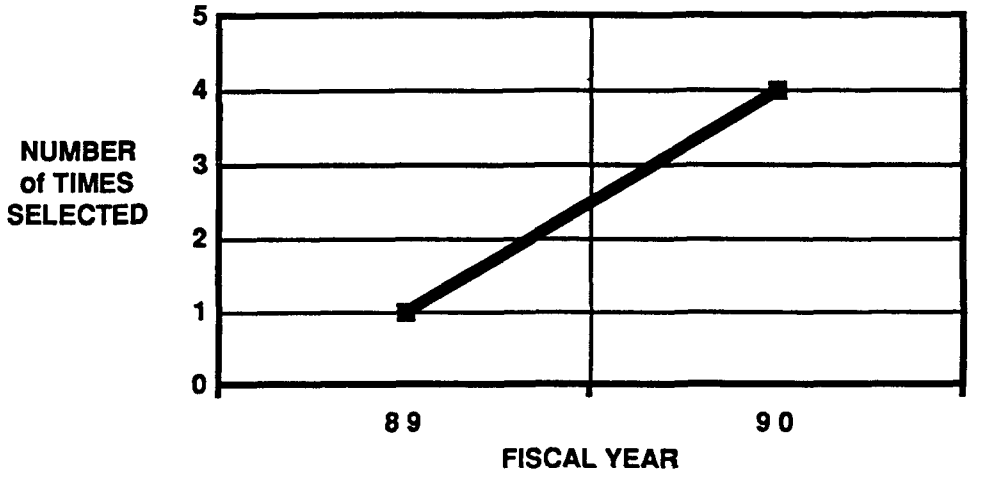
Characteristics Impacting Process Feasibility	Reason for Potential Impact	Data Collection Requirements
Presence of ground water and soil permeability less than 1×10^{-5} cm/sec	Severely limits economic practicality because much energy will be expended in driving off water.	Percolation test/water table mapping
Buried metals (drums) occupying over 90% of linear distrance between electrodes	Buried metals can result in a conductive path that would lead to electrical shorting between electrodes.	Site mapping
Loosely packed rubbish, buried coal	May start underground fire.	Site mapping
Combustible liquids* (9600 lb/yd of depth or 7 wt %)	Time-ordered limits to the capacity of the off-gas system to contain combustion gas. Not cumulative capacity.	Site mapping, analysis for priority pollutants, feasibility testing
Combustible solids* (6400 lb/yd of depth or 4.7 wt %, including 30% soil with the solids)	Time-ordered limits to the capacity of the off-gas system to contain combustion gas. Not cumulative capacity.	Site mapping, analysis for priority pollutants, feasibility testing
Combustible packages* (1.2 yd^3 or 32 ft^3)	Time-ordered limits to the capacity of the off-gas system to contain combustion gas. Not cumulative capacity.	Site mapping, analysis for priority pollutants, feasibility testing
Volatile metal content and depth	Retention of volatile metals in melt is reduced as surface is approached. Clean soil may be placed on top to increase depth to which off-gas treatment may be relied on.	Site mapping, analysis for Cd, Pb, Hg, As
Combustible liquids	9600 lb/yd of depth or 7% by weight.	
Void volumes	5-6 yd^3 or 152 ft^3.	

* Concentration limits are generic in nature; individual applications need to be reviewed in detail.

Source: Technology Screening Guide for Treatment of Soils and Sludges EPA/540/2-88/004 (1988)

Selection Frequency*

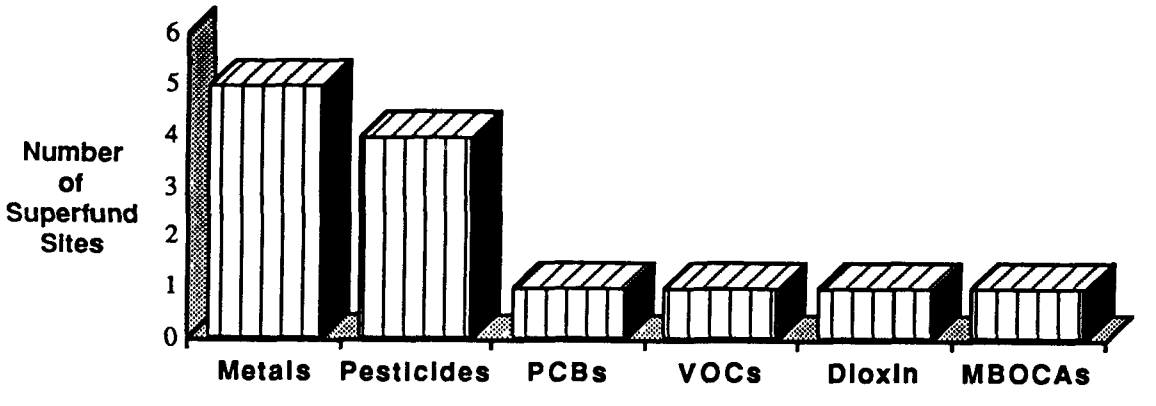
In Situ Vitrification



* *Data derived from 1982 - 1990 Records of Decision (RODs) and anticipated design and construction activities.*

September 1991

Contaminants Treated By In Situ Vitrification



* *Data derived from 1982 – 1990 Records of Decision (RODs) and anticipated design and construction activities. At some sites, the treatment is for more than one major contaminant.*

In situ Vitrification

Region	Site Name, State, Region (ROD Date)	Specific Technology	Site Description	Media (Quantity)	Key Contaminants Treated	Status	Lead Agency and Treatment Contractor (if available)	Contacts/ Phone
5	Anderson Development, MI (09/28/90)	In situ Vitrification (Thermal desorption being considered)	Chemical Manufacturing Facility Waste Lagoon	Soil, Sludge, and Clay (4000 cy)	MBOCAs (4' Methylene Bis-dichloroaniline)	Predesign; treatability study underway	PRP Lead	Mike Valentino 312-886-4785 FTS 886-4785
5	Ionia City Landfill, MI* (09/29/89)	In situ Vitrification	Municipal Landfill	Soil, Debris (5,000 cy combined)	VOCs (Methylene Chloride, Styrene, Toluene, 1-1-1 Trichloroethane), and Lead	In design	PRP Lead	Michael Gifford 312-886-7257 FTS 886-7257
5	Parsons Chemical (ETM Enterprise), MI (Emergency Response)	In situ Vitrification	Agricultural chemical facility	Soil (2,000 cy)	Dioxin, Pesticides, and Mercury	Waste staging in final stages; treatment postponed until Summer 1993	Fund Lead; Geosafe	Len Zentack 312-886-4246 FTS 886-4246
5	Sangamo/Crab Orchard National Wildlife Refuge, IL (08/01/90)	In situ Vitrification (Alternative is incineration)	Federal Facility	Soil, Sediments (38,400 cy combined)	PCBs and Metals (Lead and Cadmium)	Predesign; Design completion planned Summer '94	PRP Lead	Mary Logan 312-353-9288 FTS 353-9288
6	Crystal Chemical, TX (09/27/90)	In situ Vitrification (Technology being reconsidered)	Herbicide Manufacturing	Soil, Sediments (16,500 cy combined) (15' deep)	Arsenic	Predesign	Fund Lead/In negotiation	Lisa Price 214-655-6735 FTS 255-6735
8	Rocky Mountain Arsenal (OU 16), CO (02/26/90)	In situ Vitrification	Federal Facility	Soil (4,600 cy), Sludge (5,800 cy)	Metals (Arsenic and Mercury) and Pesticides	In design; Design completion planned Fall '91	PRP Lead; (US Army)	Linda Jacobson 303-294-1977 FTS 330-1977

* Indicates that a treatability study has been completed.

Note: Contacts listed are EPA regional staff unless otherwise indicated.

United States Environmental Protection Agency | Solid Waste And Emergency Response (OS-220) | Directive 9200 5-251FS November 1989

EPA

Innovative Technology

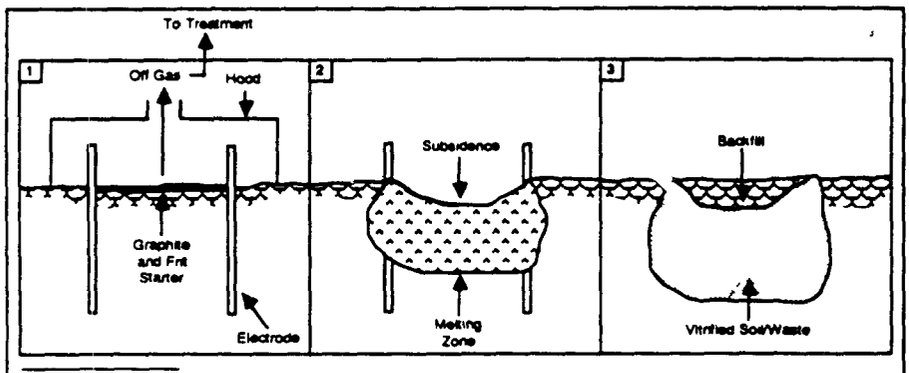
In-Situ Vitrification

TECHNOLOGY DESCRIPTION

In-situ vitrification (ISV) can be used to treat soils and sludges contaminated with mixtures of various waste types (e.g., radioactive, inorganic, and/or organic). The process electrically melts the waste media, creating an extremely stable glass-like solid.

A schematic diagram of a typical ISV treatment facility is shown in Figure 1. Four electrodes connected to a utility distribution system or to an on-site diesel generator are inserted into the soil. Because soil typically has low electrical conductivity, flaked graphite and glass frit are deposited between electrodes to provide a starter path for the electrical current. As the current flows between electrodes, the adjacent soil is heated to 1600 - 2000°C, well above a typical soil's melting temperature. The graphite starter path eventually burns off and the current is transferred to the now highly conductive melted soil.

Figure 1: Schematic Diagram of a Typical In-Situ Vitrification Treatment Facility



Note adapted from Battelle Pacific Northwest Laboratories, for Booz, Allen & Hamilton Inc

Within the melt, organic contaminants are vaporized and pyrolyzed (i.e., thermally decomposed); the pyrolysis products rise to the surface and combust in the presence of oxygen. Non-volatile inorganic elements are dissolved or incorporated into the melt. Volatile metals may vaporize and rise to the surface along with the pyrolysis products. Table 1 lists the effectiveness of ISV on general contaminant groups.

A negatively pressurized hood placed over the process area collects both organic and inorganic gases, which are treated before being released into the atmosphere. An off-gas treatment system is designed to handle conditions at most sites. If necessary, the treatment system may be modified to meet specific site requirements. The off-gas treatment may include any of the following units: a wet scrubber system, a heat exchanger with a glycol cooling system, a heater, a filter, and/or an activated charcoal assembly. The hood draws in large amounts of outside air which helps to oxidize combustible vapors and pyrolysis products. All equipment involved with the ISV process, including the off-gas treatment system, are contained in three mobile trailers.

When the treatment is completed, the power is shut off and the equipment (i.e., electrodes and hood) is moved to another treatment area where the treatment process is repeated. Following treatment, the surface of the vitrified area is covered with clean soil, and the melt is allowed to cool slowly, producing an amorphous solid resembling obsidian. Several months are required for the treated area to cool to ambient temperature; however, after four to five days, the melt has cooled sufficiently for equipment to be moved onto the treated area.

The advantages of ISV include the potential ability to destroy, remove, or immobilize all contaminant groups and to reduce the volume of the waste/media being treated. The need for off-gas collection and treatment, however, is a disadvantage.

SITE CHARACTERISTICS AFFECTING TREATMENT FEASIBILITY

Generally, the acceptable levels for treatment of contaminants in soil are 5 to 10 weight percent organics and 5 to 15 weight percent inorganics. Due to the need to consider several other factors (e.g., soil type) in determining feasibility, treatability tests are required.

The ISV process can be used to treat saturated soils; however, the water must be evaporated first, requiring additional energy and further expense. If the soil permeability is high and the soils are recharged by an aquifer, a ground water diversion system may need to be installed, adding additional expense.

Table 1
Effectiveness of In-Situ Vitrification Treatment on General Contaminant Groups for Soil and Sludge

	Treatability Groups	Effectiveness
Organics	Halogenated volatiles	◒
	Halogenated semi-volatiles	◒
	Non-halogenated volatiles	◒
	Non-halogenated semi-volatiles	◒
	PCBs	◒
	Pesticides	◒
	Dioxins/Furans	◒
	Organic cyanides	◒
	Organic corrosives	◒
Inorganics	Volatile metals	◒
	Non-volatile metals	◒
	Asbestos	◒
	Radioactive materials	●
	Inorganic corrosives	◒
	Inorganic cyanides	◒
Reactive	Oxidizers	◒
	Reducers	◒

● Demonstrated Effectiveness ◒ Potential Effectiveness ○ No Expected Effectiveness X Potentially Detrimental

The presence of significant amounts of buried metals (e.g., drums) may cause shorting between electrodes, therefore, the metal concentration limit is 5 to 16 percent of the melt weight. Additionally, metals cannot occupy more than 90 percent of the continuous linear distance between electrodes. Table 2 lists those factors that affect ISV feasibility.

TECHNOLOGY CONSIDERATIONS

Currently, ISV technology can be used to treat a maximum area of 30 ft. x 30 ft.; the maximum depth of treatment is 30 ft. Note that the maximum mass of contaminated material that can be treated per setting is 800 to 1,000 tons. When processing a 30 ft. x 30 ft. area, the mass limit will be reached before the depth reaches 30 ft.; consequently, it is impossible to reach all three maximums simultaneously. Conversely, the minimum area that can be treated is 10 ft. x 10 ft.; the recommended minimum depth of treatment is 5 to 7 ft.

Most soil types contain sufficient glass-forming materials (e.g., silicon and aluminum oxides) for treatment to be effective; however, it may be necessary to add a fluxing material (e.g., sodium carbonate) to supply adequate amounts of monovalent cations to provide sufficient electric conductivity. During ISV, the soil volume decreases 20 to 40 percent necessitating the backfilling of the subsided area with clean soil.

During full-scale operation, ISV processes 4 to 6 tons of soil per hour, requiring 0.3 to 0.5 kwh per pound of soil. The power level required is 1.9 Mw/phase.

The base price of a typical treatability study, conducted in Geosafe Corporation's laboratory, is estimated to be $25,000. Analytical costs, however, can raise the total cost to between $35,000 and $100,000.

TECHNOLOGY STATUS

Battelle Memorial Institute is exclusively licensed by the U.S. Department of Energy (DOE) to perform ISV. Geosafe Corporation, primarily owned by Battelle, holds the exclusive sublicense to perform ISV commercially. More information concerning Geosafe is found in Table 3. Battelle and Geosafe have cumulatively performed more than 70 tests of various scales for DOE and other clients. At the DOE Hanford Site in Washington State, ISV successfully treated soils contaminated with radioactive wastes.

The ISV process has been selected for evaluation under the SITE Program. Formal demonstration and testing of the process has been postponed until the developer has obtained funding for a demonstration at an appropriate site.

Currently, EPA's Emergency Response Division in Region 5 has selected ISV to treat pesticides, heavy metals, and low-level dioxins. ISV has also been selected to treat contaminated soils at the Ionia Landfill in Region 5 and the Northwest Transformers site in Region 10. The status of ISV application at CERCLA sites is summarized in Table 4.

Table 2
Site-specific Characteristics and Impacts on In-Situ Vitrification Treatment

Characteristics Impacting Process Feasibility	Reasons for Potential Impact	Actions to Minimize Impacts
Presence of ground water	Water affects the efficiency of the vitrification process, limits economic practicality	Dewater before treatment or pump to lower water table
Soil permeability greater than 1×10^{-5} cm/sec	Soil is re-saturated faster than water can be evaporated	Install ground water diversion system
Buried metals (e.g., drums), greater than 5 to 15 percent of the melt weight between electrodes	Buried metals can result in a conductive path that would lead to shorting between electrodes	Use feeding electrodes
Loosely packed rubbish and/or buried coal	May start underground fire	Install barrier walls or sheet piling
Combustible liquids, greater than 9,600 lb/yd of depth or 5 to 10 percent by weight	Time-ordered limits to the capacity of the off-gas system to contain combustion gas, (not cumulative capacity)	Increase hood capacity, process at a slower rate, or employ smaller process setting volumes
Combustible solids (e.g., wood), greater than 6,400 lb/yd of depth or 4.7 percent by weight	Time-ordered limits to the capacity of the off-gas system to contain combustion gas, (not cumulative capacity)	Increase hood capacity, process at a slower rate, or employ smaller process setting volumes
Combustible packages (e.g., boxes of clothing packaged for disposal), greater than 32 ft^3	Time-ordered limits to the capacity of the off-gas system to contain combustion gas, (not cumulative capacity)	Increase hood capacity, process at a slower rate, or employ smaller process setting volumes
Volatile metal content and depth	Retention of volatile metals in melt is less near surface than further below	Before treatment, place clean soil on top to increase melt depth
Void volumes greater than 152 ft^3	Time-ordered limits to the capacity of the off-gas system to contain combustion gas, (not cumulative capacity)	Increase hood capacity, process at a slower rate, or employ smaller process setting volumes

OFFICE OF RESEARCH AND DEVELOPMENT CONTACTS

Further information regarding the ISV process may be obtained from Steve James, U.S. EPA, Risk Reduction Engineering Laboratory, Cincinnati, Ohio 45268, (513) 569-7877 or FTS (684-7877).

Table 3
Vendor Information

Company	Contact	Address
Geosafe Corporation	James Hansen Dale Timmons	303 Parkplace Suite 126 Kirkland, WA 98033 (206) 822-4000
Note: Geosafe Corporation is the exclusive commercial sublicensee of the ISV process.		

Table 4
In-Situ Vitrification Status at CERCLA Sites

SELECTED:		
Region 5 - Ionia Landfill, MI 9/89	Heavy metals, organics in Soil	5000 cubic yards
Region 5 - Parsons/ETM, MI (Removal Action) FY90	Pesticides, heavy metals, low-level dioxins in Soil	Not Provided
Region 10 - Northwest Transformers, WA 9/89	PCBs in Soil	Not Provided

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The National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
(800) 336-4700

Reprint requests for all other documents should be directed to the specific publishing company, university, institute, or journal listed.

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10.0 GROUND WATER TREATMENT TECHNOLOGIES

10.1 TECHNOLOGY DESCRIPTION

The innovative technologies discussed in the previous sections of this document are primarily source control technologies. These technologies treat hazardous contaminants found in soils, sludges, or debris. Several additional technologies could be considered at sites where ground water is contaminated. At these sites the nature of the contaminats (concentration, partition, coefficient, solubility, viscosity, and biodegradability) and the hydrogeology (extent of contamination, hydraulic conductivity, storage coefficient, heterogeneity of the aquifer) will determine which treatment technology offers the best possibility of effectively and efficiently treating the ground water. A thorough investigation of the subsurface conditions is necessary to design a ground water treatment system, develop appropriate operating and monitoring procedures and establish realistic termination criteria.

Technologies to clean up ground water contaminated with hazardous wastes may be considered in two categories; those that rely on pumping followed by treatment above the ground and those that treat the water in situ. Exhibit 1 shows the different technologies for ground water treatment. In many ways, the technologies that are applied above ground closely resemble the traditional water treatment technologies used to treat industrial and municipal waste waters; they include such things as carbon adsorption, air stripping, chemical precipitation, biological treatment, etc.

The effectiveness of these ex situ technologies is based on the effectiveness of the pumping system in capturing the hazardous wastes and bringing them to the surface with the ground water for treatment. If pumping can not remove the contaminants from the particles within the aquifer, the ex situ treatment technologies do not have an opportunity to treat them.

Innovative technologies may be used to enhance extraction of the contaminants. These technologies include such techniques as steam extraction and surfactant flushing.

Innovative technologies may also be used to treat the ground water in situ. As with the technologies to treat soil, these technologies act to either separate the contaminants from the ground water and surrounding aquifer, change the contaminants into a less toxic or less mobile form or degrade them to eliminate their toxicity.

10.2 TECHNOLOGY STATUS

- Exhibit 2 shows the status of technologies for ground water remediation. Most of the technologies shown in Exhibit 1 and 2 are described in the documents included as Exhibit 3 through Exhibit 14. Two new technologies for the remediation of ground water which are not discussed in those documents are described in Sections 10.7 and 10.8.

- Pump and treat remedies are commonly selected in the Superfund program. For FY 89 alone, for example, 67 RODs involving pump and treat remedies were signed.

- In situ bioremediation to destroy contaminants in ground water has been selected for five Superfund sites. The contaminants to be degraded include VOCs, SVOCs, creosote, and PAHs.

10.3 APPLICATIONS

Pump and Treat

- Technologies which rely on extracting the contaminants with the ground water and separating them work best for mobile contaminants (K_{ow} <3.5), in homogeneous aquifers with high permeability. These conditions are most conducive to the extraction of the contaminants with the ground water, making them available for treatment.

- Enhancements to traditional pump and treat technologies included pulsed pumping, reinjection, chemical extraction and steam extraction. These enhancements promote more efficient removal/treatment of less mobile contaminants in less homogeneous, less permeable aquifers.

In Situ Remediation

- In situ remediation techniques (dewatering with vacuum extraction, steam extraction, chemical oxidation and bioremediation) are applicable to organic contaminants that are volatile or semivolatile or subject to oxidation or biodegradation, respectively.

10.4 TECHNOLOGY STRENGTHS AND LIMITATIONS

- Most of the technologies available for treating ground water are discussed at length in the attached documents. The strengths, limitations and waste characteristics affecting treatment are described in detail. Those technologies not described (horizontal wells and permeable treatment zones) are described in Sections 10.5 and 10.6.

10.5 HORIZONTAL WELLS FOR IN SITU REMEDIATION

The Department of Energy (DOE) has developed a new remediation technology, known as in situ air stripping, to remove chlorinated solvents from soil and ground water. The first field application of the process will demonstrate the removal of trichloroethylene from soil and ground water beneath a leaky abandoned process sewer line at the Savannah River Site in South Carolina. The process combines vapor extraction and air injection using horizontal wells. The combination of vapor extraction and air injection will allow for concurrent remediation of both the ground water and the overlying soil.

Horizontal wells have been installed in oil fields to inject steam and carbon dioxide gas to improve oil production and have been used to remove gas from coal mines. The geometry of horizontal wells may improve the performance of in situ remediation technologies. Horizontal wells can provide more contact area with the contaminant plume. Because many water-bearing formations are deposited as relatively thin but extensive zones, the use of horizontal wells may improve the efficiency of delivery of reactants to or recovery of contaminants from these formations. In addition, horizontal wells can be used along linear sources of contamination and under existing facilities.

The first phase of the DOE demonstration project consists of sparging (pumping air into) the aquifer and collecting the purged chlorinated volatile organics through a second horizontal well located in the vadose zone. Testing was conducted in the summer of 1990.

The results of the first phase show success in the removal of volatile organic compounds (VOC) from the subsurface. From July 27, 1990 to December 18, 1990, almost 16,000 pounds of trichloroethylene and tetrachloroethane were removed from the soil and ground water of the test site. The extraction rate varied from 100 to 140 pounds per day depending on the rate of air injection. The concentrations of trichloroethylene in the ground water decreased from a range of 500 ppb to 1800 ppb at the beginning of the test to a range of 10 ppb to 1031 ppb at the end of the test. Concentrations in all wells decreased during while air was injected into the aquifer at a medium rate (170 scfm).

The data indicate that the performance of the system can be affected by the permeability of the subsurface layers. In the case of highly permeable subsurface layers, some of the injected gas and accompanying volatilized contaminants may travel through the areas of high permeability and escape the system rather than flow in the intended pathways. Such short circuiting may result in uncontrolled emissions through such things as monitoring wells. With subsurface layers

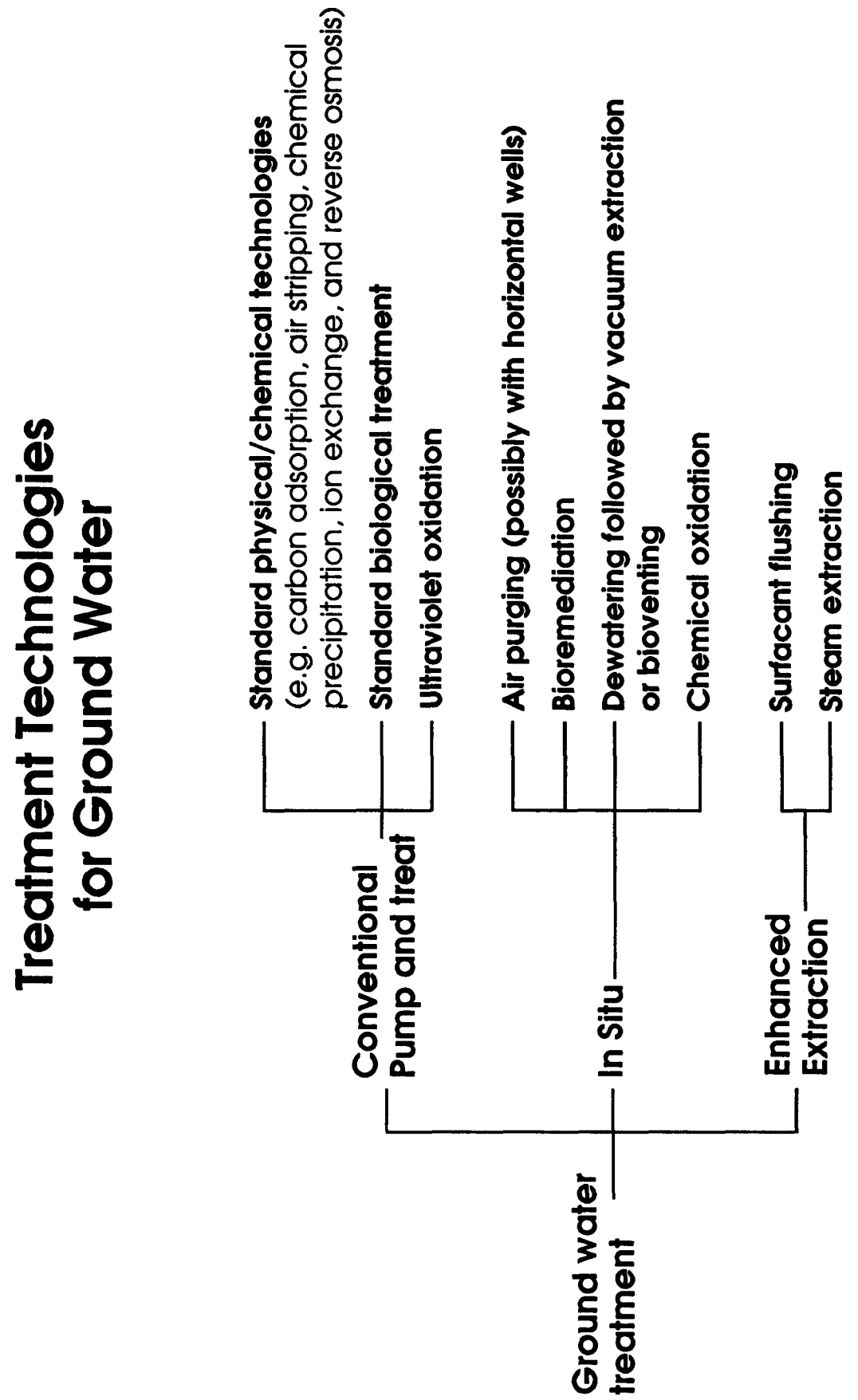
of low permeability some of the injected gas and volatilized contaminants may concentrate just below the subsurface layer.

Subsequent project phases will consist of injecting steam into the ground water and perhaps an augmented aqueous solution to enhance bioremediation.

10.6 PERMEABLE STATIONARY TREATMENT ZONES

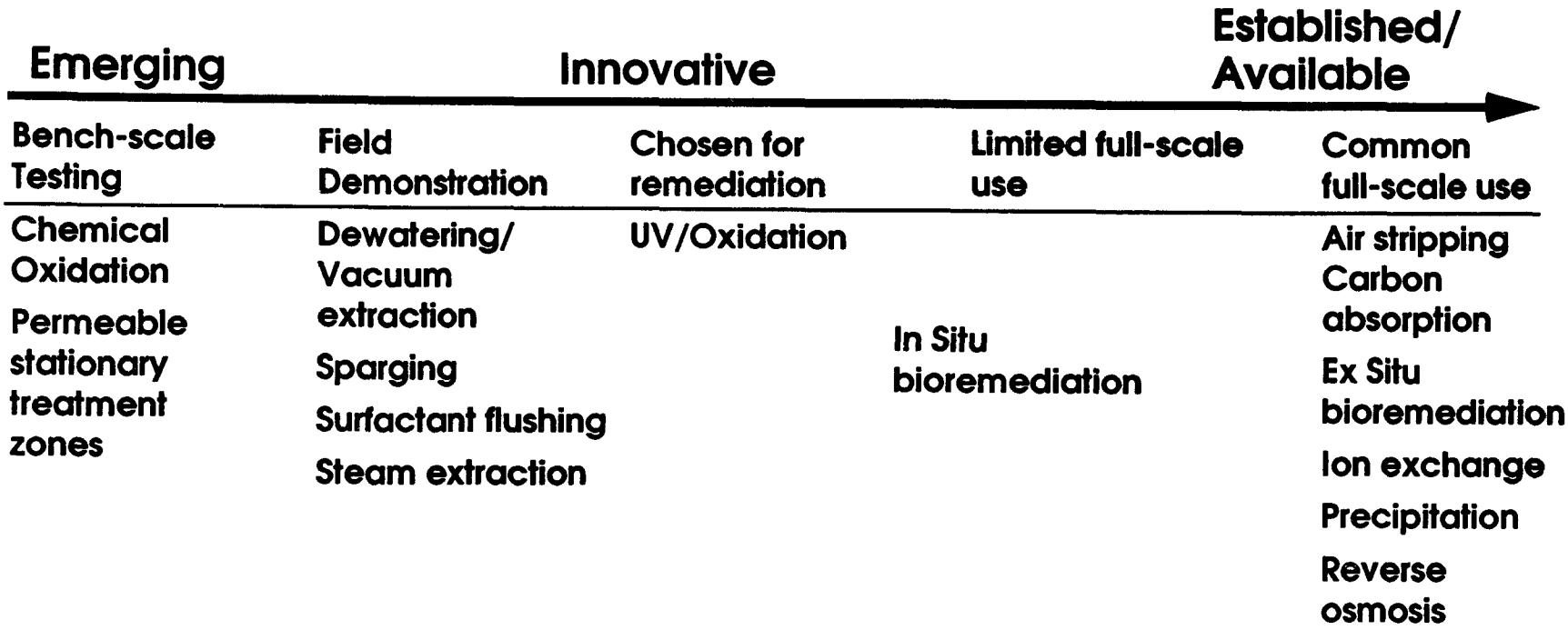
The University of Waterloo, in Ontario, Canada, is doing research into treatment zones within an aquifer that clean contaminants from ground water as it passes through the zone. This emerging technology is based on building a "curtain" within or in front of a contaminated plume in much the same fashion as a grout curtain is placed to control ground water movement. This curtain is permeable, however, and works to clean the ground water rather than control its movement. Preliminary work is being done with both chemically reactive barriers and biological walls. With a chemically reactive barrier, the contaminants in the ground water are chemically changed (i.e. dechlorinated) as they pass through the zone. If the wall is designed to promote biological degradation, they will be used to uniformly add nutrients and oxygen to the ground water system as it moves through.

Although research in the area is just beginning, these permeable treatment zones may have several theoretical advantages compared to other ground water treatment technologies. The barriers treat the ground water in situ, avoiding all the expense and difficulty of extracting the ground water and contaminants for treatment. Because the zones provide a uniform method of delivering material to the ground water system, they may avoid the problems of short circuiting sometimes found when chemicals or nutrients are delivered through a system of wells.


Treatment Technologies for Ground Water
Ground water treatment
Conventional Pump and treat
Standard physical/chemical technologies (e.g. carbon adsorption, air stripping, chemical precipitation, ion exchange, and reverse osmosis)
Standard biological treatment
Ultraviolet oxidation
In Situ
Air purging (possibly with horizontal wells)
Bioremediation
Dewatering followed by vacuum extraction or bioventing
Chemical oxidation
Enhanced Extraction
Surfacant flushing
Steam extraction

Status of Selected Technologies

For Ground Water Remediation



This chart shows the approximate status of ground water treatment technologies in terms of their application at Superfund sites.

SITE Technology Profile

DEMONSTRATION PROGRAM

E.I. DUPONT DE NEMOURS AND COMPANY OBERLIN FILTER COMPANY (Membrane Microfiltration)

TECHNOLOGY DESCRIPTION:

This microfiltration system is designed to remove solid particles from liquid wastes, forming filter cakes typically ranging from 40 to 60 percent solids. The system can be manufactured as an enclosed unit, requires little or no attention during operation, is mobile, and can be trailer-mounted.

The DuPont/Oberlin microfiltration system (Figure 1) uses Oberlin's automatic pressure filter combined with DuPont's special Tyvek filter material (Tyvek T-980) made of spun-bonded olefin. The filter material is a thin, durable plastic fabric with tiny openings (about one ten-millionth of a meter in diameter) that allow water or other liquids, along with solid particles smaller than the openings, to flow through. Solids in the liquid stream that are too large to pass through the openings accumulate on the filter, and can be easily collected for disposal.

The automatic pressure filter has two chambers -- an upper chamber for feeding waste through the filter, and a lower chamber for collecting the filtered liquid (filtrate). At the start of a filter cycle, the upper chamber is lowered to form a liquid-tight seal against the filter. The waste feed is then pumped into the upper chamber and through the filter. Filtered solids accumulate on the Tyvek surface, forming a filter cake, while filtrate is collected in the lower chamber. Air is fed into the upper chamber at about 45 pounds per square inch, and used to further dry the cake and remove any liquid remaining in the upper chamber. When the cake is considered to be dry, the upper chamber is lifted and the filter cake is automatically discharged. Clean filter material is then drawn from a roll into the system for the next cycle. Both the filter cake and the filtrate can be collected and treated further prior to disposal if necessary.

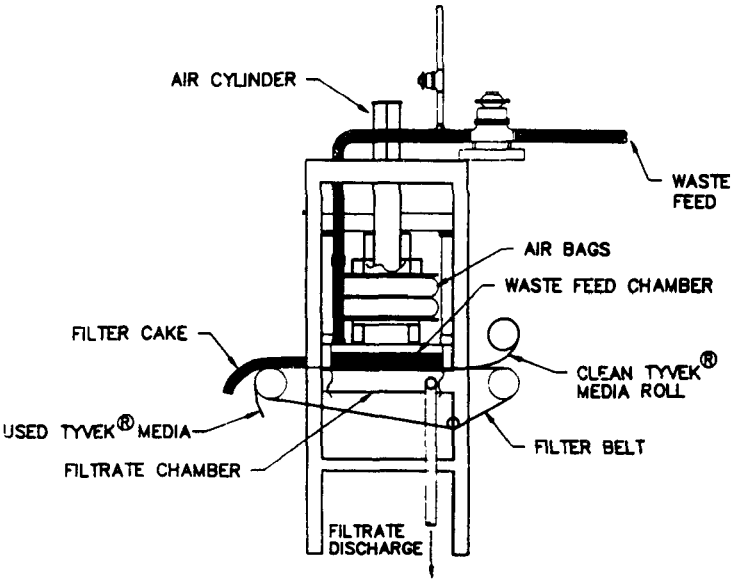


Figure 1. DuPont/Oberlin microfiltration system.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

This treatment technology is applicable to hazardous waste suspensions, particularly liquid heavy metal- and cyanide-bearing wastes (such as electroplating rinsewaters); groundwater contaminated with heavy metals; landfill leachate; and process wastewaters containing uranium. The technology is best suited for treating wastes with solid concentrations less than 5,000 parts per million; otherwise, the cake capacity and handling become limiting factors. The developers claim the system can treat any type of solids, including inorganics, organics, and oily wastes with a wide variety of particle sizes. Moreover, because the unit is enclosed, the system is said to be capable of treating liquid wastes containing volatile organics.

STATUS:

This technology was demonstrated at the Palmerton Zinc Superfund site in Palmerton, Pennsylvania. The shallow aquifer at the site, contaminated with dissolved heavy metals (such as cadmium, lead, and zinc), was selected as the feed waste for the demonstration. Pilot studies on the ground water have shown that the microfiltration system can produce a 35 to 45 percent-solids filter cake, and a filtrate with non-detectable levels of heavy metals.

The demonstration was conducted over a four-week period in April and May 1990. A Demonstration Bulletin summarizing the results at the demonstration was prepared in August 1990. A Technology Evaluation Report, Applications Analysis Report, and video of the demonstration are currently being finalized.

DEMONSTRATION RESULTS:

During the demonstration at the Palmerton Zinc Superfund site, the DuPont/Oberlin microfiltration system achieved the following results:

- Zinc and total suspended solids removal efficiencies ranged from 99.75 to 99.99 percent.
- Solids in the filter cake ranged from 30.5 to 47.1 percent.
- Dry filter cake in all test runs passed the RCRA permit filter liquids test.
- Filtrate met the applicable National Pollution Discharge Elimination System standard for zinc, but exceeded the standard for pH.
- A composite filter cake sample passed the EP Toxicity and TCLP tests for metals.

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SITE Technology Profile

DEMONSTRATION PROGRAM

TECHTRAN, INC. (Combined Chemical Binding/Precipitation and Physical Separation of Radionuclides)

TECHNOLOGY DESCRIPTION:

This chemical binding and physical separation method involves rapid, turbulent, in-line mixing of a proprietary fine powder (RHM 1000) containing complex oxides and other reactive binding agents. RHM 1000 absorbs, adsorbs, and chemisorbs most radionuclides and heavy metals in water, sludges, or soils (pre-processed into slurry), yielding coagulating, floculating and precipitating reactions. The pH, mixing dynamics, and processing rates are carefully chosen to optimize the binding of contaminants.

Water is separated from the solids using a reliable, economical, two-stage process based on: (1) particle size and density separation, using clarifier technology and microfiltration of all particles and aggregates; and (2) dewatering, using a filter press, to produce a 70 to 85 percent dry filter cake with the concentrated radionuclide(s), heavy metal(s), and other solids. The filter cake is collected and stabilized for disposal.

Figure 1 shows a diagram of the steps employed in this process for water. The amount of RHM 1000 required for processing ranges from 0.1% to less than 0.01%, depending on the application.

The process is designed for continuous through-put for water (50-1500 gal/min) or batch mode sludge and soil processing (300 tons per 8 hr. day). This technology can accommodate trace levels, naturally occurring radioactive materials (NORM), and low-level radioactive wastes. The equipment is trailer-mounted for use as a mobile field system. Larger capacity systems could be skid-mounted.

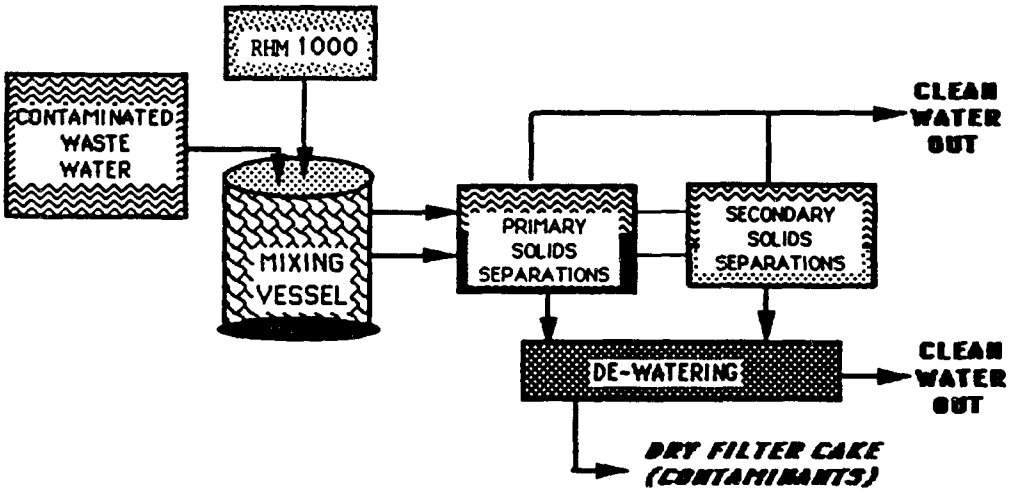

Figure 1. Schematic Diagram of Continuous Throughput for Removing Radiounuclides and Heavy Metal Contaminated Wastewater.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

The technology can be used for: (1) cleanup and remediation of water, sludges, and soils contaminated with radium, thorium, uranium and heavy metals from uranium mining/ milling operations; (2) cleanup of water containing NORM and heavy metals from oil and gas drilling; and (3) cleanup and remediation of man-made radionuclides stored in underground tanks, pits, ponds, or barrels. This technology is not applicable to water containing tritium.

STATUS:

This technology was accepted into the EPA SITE Demonstration Program in July 1990. The Department of Energy (DOE) is working with the EPA to evaluate the TechTran's chemical binding and physical separation process.

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SITE Technology Profile

DEMONSTRATION PROGRAM

EXXON CHEMICALS, INC. & RIO LINDA CHEMICAL CO. (Chemical Oxidation/Cyanide Destruction)

TECHNOLOGY DESCRIPTION:

This technology uses chlorine dioxide, generated on-site by a patented process, to oxidize organically contaminated aqueous waste streams, and simple and complex cyanide in water or solid media. Chlorine dioxide is an ideal oxidizing agent because it chemically alters contaminants to salts and non-toxic organic acids.

Chlorine dioxide gas is generated by reacting sodium chlorite solution with chlorine gas, or by reacting sodium chlorite solution with sodium hypochlorite and hydrochloric acid. Both processes produce at least 95 percent pure chlorine dioxide.

In aqueous treatment systems (Figure 1) the chlorine dioxide gas is fed into the waste stream via a venturi, which is the driving force for the generation system. The amount of chlorine dioxide required depends on the contaminant concentrations in the waste stream and the concentration of oxidizable compounds, such as sulfides.

In soil treatment applications, the chlorine dioxide may be applied in-situ via conventional injection wells or surface flushing. The concentration of chlorine dioxide would depend on the level of contaminants in the soil.

Chlorine dioxide treatment systems have been applied to drinking water disinfection, food processing sanitation, and as a biocide in industrial process water. Since chlorine dioxide reacts via direct oxidation rather than substitution (as does chlorine), the process does not form undesirable trihalomethanes.

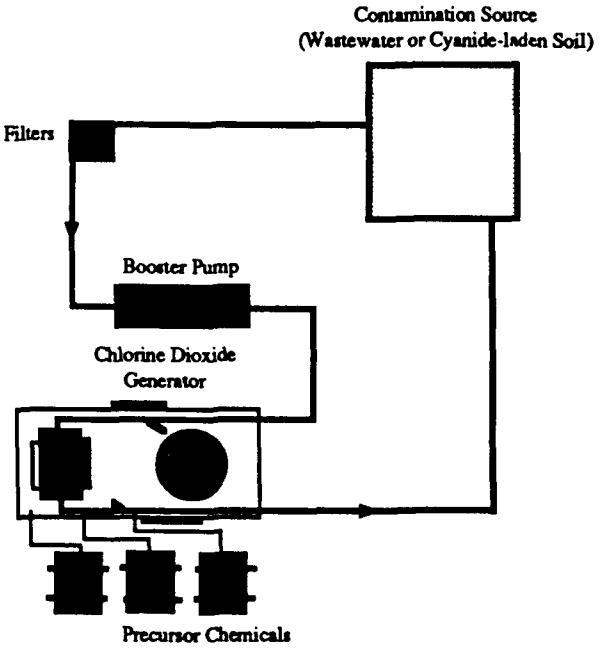

Figure 1. Typical treatment layout.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

This technology is applicable to aqueous wastes, soils, or any leachable solid media contaminated with organic compounds. It can also be applied to groundwater contaminated with pesticides or cyanide; sludges containing cyanide, PCPs or other organics; and, industrial wastewater similar to refinery wastewater.

STATUS:

The SITE program has accepted two proposals from Exxon Chemicals, Inc. and Rio Linda Chemical Company to perform two separate demonstrations: one of cyanide destruction and the other of organics treatment. Site selection for these demonstrations is currently underway

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SITE Technology Profile

DEMONSTRATION PROGRAM

ULTROX INTERNATIONAL
(Ultraviolet Radiation/Oxidation)

TECHNOLOGY DESCRIPTION:

This ultraviolet (UV) radiation/oxidation process uses UV radiation, ozone (O_3) and hydrogen peroxide (H_2O_2) to destroy toxic organic compounds, particularly chlorinated hydrocarbons, in water. The process oxidizes compounds that are toxic or refractory (resistant to biological oxidation) in concentrations of parts per million or parts per billion.

The Ultrox system consists of a reactor module, an air compressor/ozone generator module, and a hydrogen peroxide feed system. It is skid-mounted and portable, and permits on-site treatment of a wide variety of liquid wastes, such as industrial wastewaters, ground waters, and leachate.

The reactor size is determined from the expected wastewater flow rate and the necessary hydraulic retention time to treat the contaminated water. The approximate UV intensity, and ozone and hydrogen peroxide doses are determined from pilot-scale studies.

Influent to the reactor (Figure 1) is simultaneously exposed to UV radiation, ozone, and hydrogen peroxide to oxidize the organic compounds. Off-gas from the reactor passes through an ozone destruction (Decompozon) unit, which reduces ozone levels before air venting. The Decompozon unit also destroys gaseous volatile organic compounds (VOC) stripped off in the reactor. Effluent from the reactor are tested and analyzed before disposal.

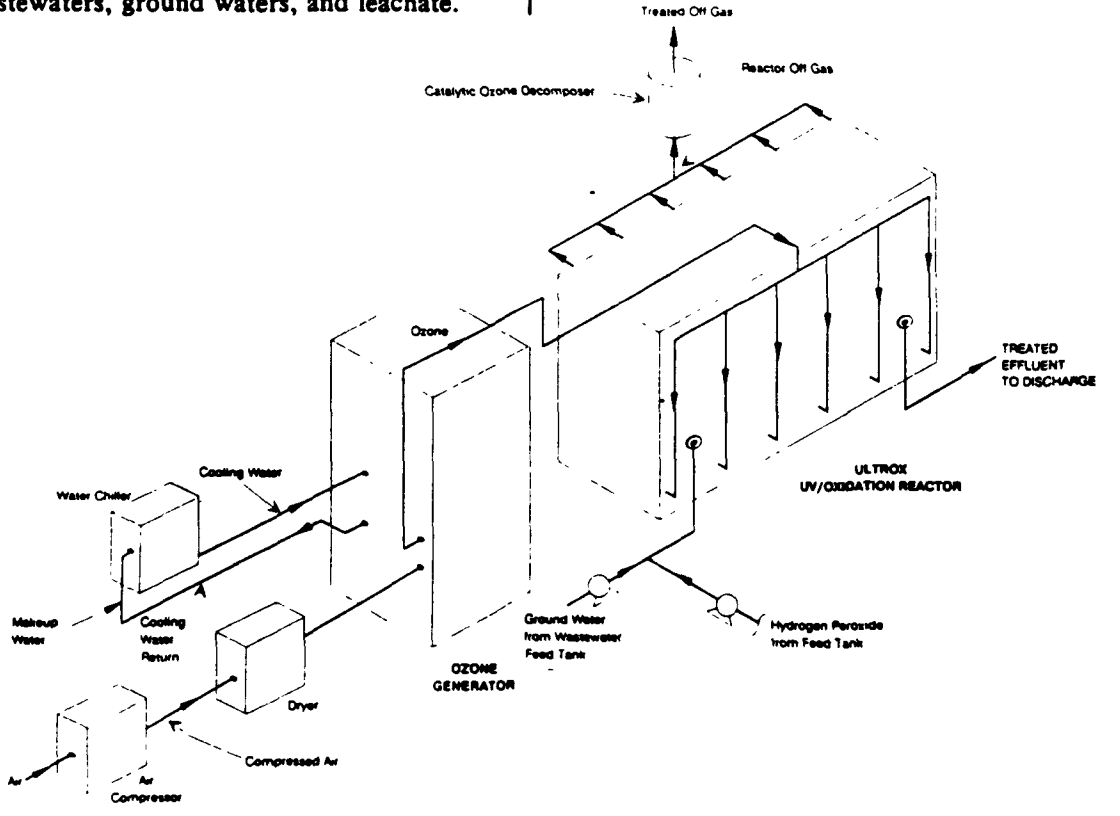

Figure 1 Isometric view of Ultrox system

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

Contaminated ground water, industrial wastewaters and leachates containing halogenated solvents, phenol, pentachlorophenol, pesticides, PCBs, and other organic compounds are suitable for this treatment process.

STATUS:

A field-scale demonstration was completed in March 1989 at a hazardous waste site in San Jose, California. The test program was designed to evaluate the performance of the Ultrox System at several combinations of five operating parameters: (1) influent pH, (2) retention time, (3) ozone dose, (4) hydrogen peroxide dose, and (5) UV radiation intensity. The Technology Evaluation Report was published in January 1990 (EPA/540/A5-89/012). The Applications Analysis Report is being published and should be available in December 1990.

DEMONSTRATION RESULTS:

Contaminated groundwater treated by the Ultrox system met regulatory standards at the following operating conditions:

Retention time	-	40 minutes
Influent pH	-	7.2 (unadjusted)
O_3 dose	-	110 mg/L
H_2O_2 dose	-	13 mg/L
UV lamps	-	all 24 operating at 64 watts each

Out of 44 VOC samples, three were chosen to be used as indicator parameters. The VOC removal efficiencies at these conditions are presented in Table 1.

TABLE 1
PERFORMANCE DATA FOR REPRODUCIBLE RUNS

	Mean Influent (µg/L)	Mean Effluent (µg/L)	Percent Removal
Run 9			
TCE	65	1.2	98
1,1-DCA	11	5.3	52
1,1,1-TCA	4.3	0.75	83
Total VOCs	170	16	91
Run 12			
TCE	52	0.55	99
1,1-DCA	11	3.8	65
1,1,1-TCA	3.3	0.43	87
Total VOCs	130	12	92
Run 13			
TCE	49	0.63	99
1,1-DCA	10	4.2	58
1,1,1-TCA	3.2	0.49	85
Total VOCs	120	20	83

Removal efficiencies for TCE were about 99 percent. Removal efficiencies for 1,1-DCA and 1,1,1-TCA were about 58 percent and 85 percent, respectively. Removal efficiencies for total VOCs were about 90 percent.

For some compounds, removal from the water phase was due to both chemical oxidation and stripping. Stripping accounted for 12 to 75 percent of the total removal for 1,1,1-TCA and 5 to 44 percent for 1,1-DCA. Stripping was less than 10 percent for TCE and vinyl chloride, and was negligible for other VOCs present.

The Decompozon unit reduced ozone to less than 0.1 ppm (OSHA standards), with efficiencies greater than 99.99 percent. VOCs present in the air within the treatment system, at approximately 0.1 to 0.5 ppm, were not detected after passing through the Decompozon unit.

Very low TOC removal was found, implying that partial oxidation of organics occurred without complete conversion to CO_2 and H_2O.

The average electrical energy consumption was about 11 kW/hour of operation.

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SITE Technology Profile

DEMONSTRATION PROGRAM

ALLIED SIGNAL CORPORATION
[formerly Detox, Inc.]
(Submerged Aerobic Fixed-Film Reactor)

TECHNOLOGY DESCRIPTION:

This biological treatment system relies on aerobic microbial processes to metabolize contaminants present in a liquid waste stream. The system can treat liquids containing low concentrations (<20 parts per million, ppm) of readily biodegradable materials and yield concentrations in the low parts per billion (ppb) range.

The biological treatment system consists of an above ground fixed-film reactor, supplemental nutrient storage tank and pump, sump tank with pump, cartridge filter, and final activated-carbon filter. High surface area plastic media is used to fill the reactor, and the water level within the reactor is set to cover the plastic media. Bacterial growth is attached as film to the surface of the plastic media.

The bioreactor is operated on a one-pass, continuous-flow basis, at hydraulic retention times as low as one hour. The process begins (Figure 1) when contaminated water from a well or equalization tank is pumped into the bioreactor. The influent waste stream is evenly dispersed over the reactor packing by a header-distribution system. As the waste stream passes through the reactor, the biofilm removes the biodegradable organics. An air distribution system below the plastic media supplies oxygen to the bacteria in the form of fine bubbles. An effluent water header system collects water from the bottom of the reactor after it has been treated. Water exiting the reactor is first passed through a cartridge filter, to remove any excess biological solids, followed by activated carbon treatment, to further remove any remaining organic compounds. Depending upon the effluent water discharge criteria, the cartridge and carbon filters may not be needed.

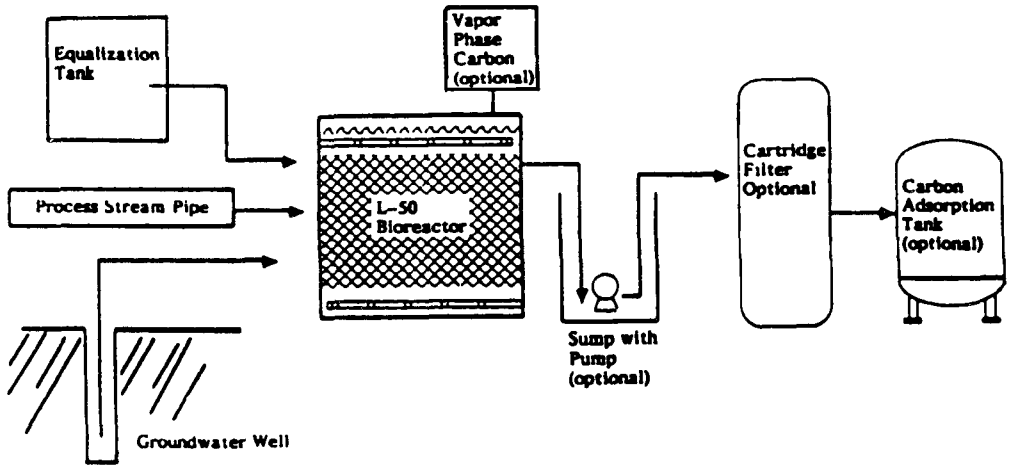

Figure 1. Proposed Detox biological treatment system.

Source: The Superfund Innovative Technology Evaluation Program: Technology Profiles, EPA/540/5-90/006 (1990).

WASTE APPLICABILITY:

This technology is typically used to treat groundwater and industrial process waters, but is also applicable to contaminanted lagoon and/or pond waters. The water to be treated must fall within a pH of 6.5 to 8.5, a temperature of 60-95°F, and be free of toxic and/or inhibitory compounds, including certain metals. Readily biodegradable compounds such as methyl ethyl ketone (MEK) and benzene can be treated, along with some organic chemicals that are initially more resistant to biodegradation, such as chlorobenzene. Halogenated compounds (such as tetrachloroethylene, trichloroethylene, and chloroform) are not readily biodegraded and cannot be treated by this system.

STATUS:

Treatability tests are being conducted to determine whether the G&H Landfill NPL site in Utica, Michigan will be suitable for the demonstration of this process. If this site is selected, the demonstration is expected to start in late Spring or Summer 1991.

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United States Environmental Protection Agency
Office of Emergency and Remedial Response Washington, DC 20460
EPA/540/2-90/011 September 1990

Superfund

EPA

Subsurface Contamination Reference Guide

EPA/540/2-90/011
September 1990

SUBSURFACE CONTAMINATION REFERENCE GUIDE

Office of Emergency and Remedial Response
U.S. Environmental Protection Agency
Washington, DC 20460

NOTICE

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Chapter 1
INTRODUCTION

Ground water contamination is a significant concern at approximately 70% of the Superfund sites. The difficulties associated with cleaning up contaminated ground water are becoming more and more evident as experience with this problem increases. A recent study of 19 ground water extraction systems (U.S. EPA, 1989, EPA/540/2-89/054) indicated several factors that can limit the effectiveness of the traditional pump-and-treat remediation systems and also identified possible enhancements than may improve the performance of these systems. Many of the factors limiting performance are a result of interactions between the contaminants and the subsurface environments and can be tied to particular contaminant properties (e.g., solubility, density) and/or the nature of the subsurface (e.g., low permeability, fractures).

As a result of the referenced study several recommendations were made including a recommendation to collect more detailed data on the vertical stratigraphy of the subsurface, the vertical variations in contaminant concentration, and the proportion of contaminant sorbed to the soil in the saturated zone. To the extent possible potential limitations should be recognized even before the investigation begins; i.e. during scoping, to better focus remedial investigation/feasibility study (RI/FS) efforts.

This guide was developed to provide a source of information pertaining to important fate and transport properties for a variety of contaminants commonly found in ground water at Superfund sites. This information may help to focus site investigation efforts and identify early-on potential remediation strategies. Knowledge pertaining to the magnitude of these properties can be used to help to project whether contaminants will sorb significantly to soils, dissolve and move with ground water flow, migrate downward as a separate phase, or float on the water table. Potential remedial technologies have been identified for various combinations of contaminant types and hydrogeological environments.

Information pertaining to contaminant fate and transport properties are presented in tabular form and provided as fold-out charts for easy reference.

This document was prepared as a task of the Subsurface Remediation Information Center located at the U.S. EPA Robert S. Kerr Environmental Research Laboratory (RSKERL), Ada, Oklahoma. Questions pertaining to the information contained in this document should be addressed to John E. Matthews at RSKERL-Ada (405/332-8800).

Chapter 2
SUBSURFACE REMEDIAL TECHNOLOGIES

Subsurface remedial technologies which may be applicable at Superfund sites are described below. These descriptions are intended as guidance for use in conjunction with the tabular data presented in the foldout charts (Tables 2 and 3).

2.1 PUMP AND TREAT

2.1.1 Continuous Pumping

Pump and treat remediation technology is applicable to the saturated zone and refers to the extraction of contaminated ground water from the subsurface and subsequent treatment of the extracted ground water at the surface. Extraction of contaminated ground water is accomplished through the use of extraction (pumping) wells which are completed at specified locations and depths to optimize contaminant recovery. Determination of the locations and depths of extraction wells requires prior delineation of the contaminant plume and knowledge of the aquifer properties. Injection wells may be installed to enhance contaminant recovery by flushing contaminants toward extraction wells.

Pump and treat technology is best suited for managing mobile chemicals (i.e., log K_{oc} or log K_{ow} values less than 3.0 and 3.5, respectively) residing in relatively permeable and homogeneous hydrogeologic settings. Factors which must be considered and may limit the ability of pump and treat remediation treatment to achieve cleanup concentrations in the ground water include: 1) the presence of chemicals with relatively high K_{oc} or K_{ow} values (e.g. log K_{oc} > 3.0 or log K_{ow} > 3.5), 2) aquifers exhibiting low permeability properties (e.g., < 10^{-6} cm/s), 3) highly heterogeneous hydrogeologic settings (e.g. highly stratified aquifers with multiple layers of coarse and fine textured material), and 4) the presence of spatially discontinuous or inaccessible dense non-aqueous phase liquid (DNAPL).

Pump and treat technology may, in many cases, be used to aid in the removal of light non-aqueous phase liquid (LNAPL) and/or DNAPL which may be present. Recovery of LNAPL residing as free product on the surface of the water table, for example, can be facilitated by using pumping wells to create cones of depression. DNAPL residing as large pools in topographical lows at the bottom of aquifers can be recovered by pumping from wells screened over the thickness of the pools. In cases where recovery is not feasible (e.g., DNAPL resides in fractures or is present as spatially discontinuous free product within an aquifer), alternative measures such as physical containment (e.g. cement-bentonite walls) should be considered.

Pumping technology may also be used as a means of containing or controlling contaminant plumes. This is accomplished through control of hydraulic gradients by selectively locating pumping wells in the area of the plume. Control of hydraulic gradients should be considered in conjunction with physical containment options.

The surface treatment of extracted ground water will vary depending on the contaminants present. Typical actions include air stripping, activated carbon adsorption and biological treatment. In some cases, treated ground water may be amended with nutrients and oxygen and reinjected into the subsurface to aid in stimulating biodegradative processes.

Pump and treat remediation technology generally will play an important role in ground water cleanup. For information regarding applicability of pump and treat technology and its modifications, contact Randall R. Ross at the RSKERL-Ada (405-332-8800).

2.1.2 Pulsed Pumping

Pulsed pumping is a modification of standard pump and treat technology which involves regular or periodic cessation of pumping activities to optimize ground water cleanup. Pulsed pumping may be necessary or more cost-effective in cases where extraction wells can not sustain yields (e.g., in bedrock and unconsolidated deposits of low permeability), where desorption and/or dissolution of contaminants in the subsurface is relatively slow, or where hydraulic conductivity heterogeneity is high. Pulsed pumping may be appropriate for: 1) low yield consolidated and unconsolidated deposits; 2) relatively homogeneous hydrogeologic settings containing contaminants with log K_{oc} values between 2.0 and 4.0 (or log K_{ow} values between 2.5 and 4.5); 3) heterogeneous formations consisting of alternating high and low permeability layers and containing contaminants with log K_{oc} and log K_{ow} values less than 3.0 and 3.5, respectively; and 4) hydrogeological settings containing low to moderately soluble residual non-aqueous phase liquid (NAPL).

A potential concern associated with implementation of pulsed pumping is the uncontrolled migration of the contaminant plume during non-pumping phases. Nearby water supply wells or irrigation systems may significantly impact the behavior of the contaminant plume during non-pumping phases and thereby create a potentially more serious contamination scenario.

2.1.3 Reinjection

Reinjection, which often is used in combination with pump and treat or pulsed pumping, generally refers to injection of treated ground water back into the subsurface. Reinjection may be accomplished through the use of injection wells or other means such as infiltration galleries. Reinjected ground water can be used to help remove contaminants residing in the unsaturated zone by forcing these contaminants towards extraction wells. Reinjection also may be used in the stimulation of biodegradative processes in the saturated zone, thereby enhancing cleanup of the saturated zone. In such cases, the injectate is amended with nutrients and an oxygen source. In special cases, the injectate may be amended with surfactants or other compounds (i.e. chemical extraction) to facilitate removal of adsorbed and residual organics in the unsaturated and/or saturated zones.

2.2 SOIL VACUUM EXTRACTION

Vacuum extraction technology involves the enhanced removal of chemicals in the subsurface through application of a vacuum. The applied vacuum enhances volatilization of compounds from soil and pore water. The technology is particularly applicable to relatively volatile organic compounds (Henry's Law Constant > 10^{-3} atm-m^3/mole) residing in the unsaturated zone. The technology also is applicable for removal of volatile light non-aqueous phase liquids (LNAPLs) floating on the water table or entrained in the capillary fringe. The process involves installation of vacuum extraction wells at strategic locations and depths. The spacing of extraction wells is dependent on soil properties such as permeability and porosity. The technology is applicable to most soil types although removal efficiency will generally decrease with decreasing soil permeability and increasing subsurface stratigraphy (heterogeneity).

Vapors released from the subsurface as a result of the vacuum extraction process may be captured and then processed through a liquid-vapor separator. The separated volatile organic vapor fraction may be treated with activated carbon or other means.

Vacuum extraction also can serve a dual purpose by enhancing removal of subsurface organic contaminants through stimulation of aerobic biodegradative processes. This is accomplished by ensuring a constant and ample supply of oxygen for use by indigenous subsurface microbial populations.

Vacuum extraction also may be used in conjunction with in-situ steam extraction (see description below). Steam extraction may enhance the recovery of organic chemicals, including NAPL's, from the vadose zone.

Vacuum extraction is a proven remedial technology which is being increasingly applied at Superfund sites. For further information regarding the applicability of vacuum extraction contact Dominic DiGiulio at the RSKERL-Ada (405-332-8800).

2.2.1 In-Situ Steam Extraction

In-situ steam extraction facilitates the removal of moderately volatile (10^{-3} > v.p. > 10^{+0} mm Hg) residual organics, including NAPLs, from the vadose zone. Steam extraction technology utilizes injection of pressured steam to the contaminated horizon to thermally enhance the evaporative rate of the contaminant and its subsequent removal. Injection of steam also can be expected to enhance removal of residual NAPL's in the unsaturated zone by decreasing their viscosities. Steam extraction is an emerging technology that appears promising, particularly if used in conjunction with vacuum extraction.

2.3 SOIL FLUSHING

Soil flushing technology involves the use of extractant solvents to remove organic and/or inorganic contaminants from soils in the subsurface. Extractant solvents may include water, water-surfactant mixtures, acids, bases, chelating agents, oxidizing agents and reducing agents. The extractants used, however, should be limited to those which exhibit low toxicity and will not otherwise adversely impact the subsurface environment. Proper control measures must be exercised to prevent migration of extractant-contaminant mixtures from the vadose zone into ground water.

In-situ soil flushing can be applicable to those compounds residing in the vadose zone which are not amenable to removal by vacuum extraction. These compounds may include semi-volatile organics, cyanide salts, and metals (e.g., selenium, arsenic, and hexavalent chromium). Applications are limited to soils with adequate permeability ($k > 10^{-5}$ cm/s) and a reasonable degree of homogeneity. For semi-volatile organics amenable to biodegradation, bioremediation in concert with in-situ vacuum extraction (or alternative air circulation technology) will likely be a better choice.

The effectiveness of soil flushing relative to other vadose zone remedial technologies is not clear. Due to the potential environmental impact of in-situ soil flushing, the technology should only be used in situations where other remediation technologies of lower potential environmental impact are not appropriate.

Soil flushing has been used at some Superfund sites although the level of its success is not clear. For information regarding the applicability of soil flushing, contact John Brugger at the EPA Risk Reduction Engineering Laboratory, Edison NJ (201-321-6634).

2.3.1 Chemical Extraction

Chemical extraction as used in this document refers to a specialized form of soil flushing that applies only to the saturated zone. This technology involves the use of extractant solvents to enhance desorption or solubilization of contaminants in the saturated zone in conjunction with pump and treat operations. Extracted ground water is amended with solvents and/or other chemicals then reinjected at strategic locations into the aquifer. The extractants used are similar to those used in soil flushing in the vadose zone. Chemical extraction is most applicable in cases where contaminants are not easily mobilized or removed with water alone, i.e., strongly sorbed to aquifer solids or present as residual saturation. Caution should be exercised when using chemical extraction methods, however, because of the potential adverse impact introduced chemicals may have on the subsurface environment.

2.4 CONTAINMENT

Containment technologies are used to isolate contaminated areas in the subsurface from the surrounding uncontaminated environment. Containment usually involves installation of an impermeable barrier around, or a cap over, the affected area. The barrier may take the form of a slurry wall (e.g. soil-bentonite wall or cement-bentonite wall), a grout curtain, or sheet piling cut-offs. In the saturated zone, these barriers must be tied into an impermeable layer at the base of the aquifer. Containment, although not considered a remediation technology, warrants consideration in concert with remedial technologies or as an interim measure while remediation technologies can be considered. Spatially discontinuous DNAPL residing within an aquifer, for example, may be an appropriate scenario for considering containment. The selection of the barrier material must take into account the compatibility of the material with the contaminant(s) in question. Containment also may include installation of a cap over the contaminated area to impede infiltration of water into that area.

Another method of controlling contaminant migration is hydraulic containment. Hydraulic containment involves retardation of movement of a ground water contaminant plume by using pumping wells to control hydraulic gradients. Hydraulic

containment may be used early in a site investigation to prevent plume expansion while a more detailed characterization is completed.

For information regarding the applicability of containment technologies, contact Dr. Walter Grube at the EPA Risk Reduction Engineering Laboratory, Cincinnati, OH (513-569-7798).

2.5 BIOREMEDIATION

Bioremediation technologies involve enhancing biodegradation of contaminants in the saturated and unsaturated zones of the subsurface environment through the artificial stimulation of indigenous soil and ground water microbial populations. Natural biodegradative processes are enhanced by optimizing conditions necessary for subsurface microbes to grow and complete metabolic pathways. Bioremediation is applicable only for treating organic contaminants. Bioremediation should only be considered in conjunction with source control.

Bioremediation for subsurface contamination often can be carried out in situ. The successful execution of an in-situ bioremediation program will depend upon: 1) amenability of the organic compound(s) to biodegradation, 2) permeability and heterogenic properties of the subsurface regime, 3) ability of the delivered oxygen and nutrients to reach the contaminated area, and 4) other factors such as temperature and pH.

In situ bioremediation in the saturated zone can be applied as a specialized form of pump and treat. Extracted ground water from the contaminated zone is treated at the surface, amended with nutrients and oxygen, and then reinjected into the subsurface at strategic locations. Difficulties may arise in the dissemination of oxygen and nutrients in low permeability or highly heterogeneous regimes. Some states may not allow reinjection of treated ground water; therefore, amendments must be delivered to the injection point in clean water.

In situ bioremediation in the unsaturated (vadose) zone can be applied as a specialized form of soil vacuum extraction. The air circulation induced by soil vacuum extraction ensures an ample supply of oxygen to the indigenous microbial population. Other vadose zone in situ bioremediation systems use infiltration galleries or injection wells for delivery of oxygen and nutrients.

Bioremediation is a promising technology for vadose zone soils and contaminated ground waters . For further information regarding the applicability of bioremediation, contact John E. Matthews, Scott G. Huling or John T. Wilson at the RSKERL-Ada (405-332-8800).

2.6 IN-SITU VITRIFICATION

In-situ vitrification (ISV) transforms contaminated soil into an inert glass-like mass that is highly resistant to weathering and leaching. The technique employs electrodes and a high amperage current to heat surrounding soil from 1600 °C to 2000 °C. When operating temperatures are reached a molten mass of contaminated soil is created. As the mass expands it assimilates nonvolatile compounds into its structure and destroys volatile organic compounds by pyrolysis. The technology is generally more applicable at sites having soils contaminated with metals or organic chemicals exhibiting high K_{oc} or K_{ow} values.

In-situ vitrification is a proven technology which has been implemented at selected sites. For further information regarding the applicability of in-situ vitrification, contact Teri Shearer at the EPA Risk Reduction Engineering Laboratory, Cincinnati, OH (513-569-7949).

2.7 TREATMENT COMBINATIONS

Often it will be necessary to implement a combination of treatment technologies to effectively remediate or control subsurface contamination. An example of such a combination is pump and treat with in-situ bioremediation or chemical extraction. One of these combinations may be appropriate at sites where contaminants are strongly adsorbed within the aquifer, and pump and treat alone is expected to have limited success. In-situ bioremediation or chemical extraction could facilitate removal of the strongly sorbed contaminants, thereby enhancing the overall remediation effort. In general, in-situ bioremediation or chemical extraction would be most effective after initial recovery efforts using pump and treat alone have been completed.

Another useful treatment combination involves pump and treat and containment. This combination may be of interest in cases where DNAPL is distributed in a spatially discontinuous manner within the aquifer. Because DNAPL recovery in such a case would be very difficult, the only recourse might be to control and/or contain the contamination. Pump and treat would initially be used to draw in or reduce the size of the aqueous phase contaminant plume generated by the DNAPL. Physical containment would then be used to isolate the DNAPL source area.

An additional treatment combination which may be of interest is aquifer dewatering using pump and treat followed by soil vacuum extraction. This combination of technologies may be of use in cases where an aquifer is

contaminated with volatile organics and dewatering portions of the aquifer is feasible. Pumping would be used to dewater a portion of the aquifer so that vacuum extraction could be applied to enhance volatilization and biodegradation of the volatile organics contaminants in the dewatered zone.

Combinations involving more than two treatment technologies also should be considered in efforts to optimize cleanup of subsurface contamination.

Chapter 3
CONTAMINANT PROPERTIES AFFECTING SUBSURFACE TRANSPORT AND FATE

The following is a description of some important properties which may play an important role in the transport and fate of contaminants in the subsurface. These descriptions are intended to provide guidance for using the tabular information provided in the foldout charts (Tables 2 and 3).

Melting Point - The melting point of a compound provides an indication of the physical state of a pure compound at field temperatures. Compounds with melting points above 30°C, for example, would be expected to be immobile in pure form. Such compounds would be of primary concern when in the dissolved phase, either in water or other solvent. Compounds with melting points lower than 30°C may be present as mobile non-aqueous phase liquid.

Water Solubility - Water solubility governs the extent to which a contaminant will partition into the aqueous phase. More soluble contaminants would be expected to migrate further in the subsurface than less soluble compounds. The greater the water solubility of a compound, the greater will be the tendency for that compound to migrate with the aqueous advective flow component. Contaminants with higher water solubilities are more amenable to removal from the saturated zone by pump and treat technology. These same compounds, however, are more likely to migrate through the vadose zone to ground water.

Vapor Pressure - The vapor pressure of a compound provides an indication of the extent to which the compound will volatilize. The tendency of a compound to volatilize will rise proportionately with its vapor pressure. Compounds with higher vapor pressures are more amenable to treatment with vacuum extraction technologies. For comparative purposes, the vapor pressure of water at 20°C is 17.5 mm Hg.

Henry's Law Constant - Henry's Law Constant provides an indication of the extent to which a compound will volatilize from an aqueous solution. Henry's Law Constant is directly proportional to the vapor pressure of the compound and inversely proportional to the water solubility of the compound. The greater the Henry's Law Constant of a compound, the greater will be the tendency of the compound to volatilize from aqueous solution. Compounds with higher Henry's Law Constants are more amenable to treatment with vacuum extraction technologies.

Density - The density of a compound indicates whether the compound is heavier or lighter than water. (The density of water is approximately 1.0 g/cc). Liquid compounds with densities greater than 1.0 g/cc and of only limited water solubility (i.e. DNAPLs), may migrate vertically under the influence of gravity. DNAPLs may eventually gravitate to the bottom or other region of an aquifer where an impermeable layer is encountered. Compounds with limited water solubility and with densities less than 1.0 g/cc will tend to float on the water table.

Dynamic Viscosity - Dynamic viscosity provides an indication of the ease with which a compound (in its pure form) will flow. The mobility of the compound in pure form is inversely proportional to its dynamic viscosity. The dynamic viscosity of water is approximately 1.0 centipoise (cp).

Kinematic Viscosity - The kinematic viscosity of a compound takes into account the density of the compound and provides an indication of the ease with which the compound (in its pure form) will percolate through the subsurface. The lower the kinematic viscosity of a compound, the greater will be its tendency to migrate in a downward direction. Kinematic viscosity is of particular importance with regard to the movement of DNAPLs in aquifers. The lower the kinematic viscosity of a DNAPL, the greater will be the ease with which the DNAPL will move downwards and penetrate the finer grained layers in the subsurface. The kinematic viscosity of water is approximately 1.0 centistokes (cs).

Octanol/Water Partition Coefficient (K_{ow}) - The octanol/water partition coefficient is a measure of the extent to which a contaminant partitions between octanol and water. It is the ratio of the concentration of the compound in octanol to the concentration of the compound in water. The K_{ow} provides an indication of the extent to which a compound will adsorb to a soil or an aquifer solid, particularly organic material. The greater the K_{ow} value of a compound, the greater will be its tendency to be adsorbed in the subsurface.

Organic Carbon Partition Coefficient (K_{oc}) - The organic carbon partition coefficient is the ratio of the amount of chemical adsorbed per unit weight of organic carbon in the soil to the concentration of the chemical in solution at equilibrium. The K_{oc} is similar to the K_{ow}.

Biodegradability Potential - The biodegradability potential of a compound is important in determining the feasibility of using bioremediation as a treatment technology. The greater the biodegradability of a compound, the greater will be the susceptibility of the compound to a bioremediation process. Only aerobic biodegradability is addressed in this document.

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EPA

A Guide to Pump and Treat Ground-Water Remediation Technology

This fact sheet summarizes how to use available hydrogeological and chemical data to determine when, where, and how pump-and-treat technology can be used successfully to contain and remediate contaminant plumes. It is based on the Office of Research and Development's *Basics of Pump-and-Treat Ground-Water Remediation Technology*, EPA/600/8-90/003.

OVERVIEW

While there are several ground-water containment and cleanup options available to choose from, this fact sheet focuses on pump-and-treat technology. The pump-and-treat process is the most commonly used ground-water remediation technology at hazardous waste sites. The objectives of pump-and-treat are to reduce the concentration of contaminants to an acceptable level during cleanup or to contain contaminants in order to protect the subsurface from further contamination. Pump-and-treat systems capture contaminated ground water for surface treatment. This fact sheet outlines the basic requirements for an effective pump-and-treat system, which include identifying the contaminant, characterizing the subsurface, designing a capture system, installing extraction wells, and monitoring the remediation progress. Here the "pump" portion of the pump-and-treat process is emphasized. Recent research has identified complex chemical and physical interactions between contaminants and the subsurface media that may limit the effectiveness of the extraction phase. These important limitations of pump-and-treat technology are also described in this fact sheet.

CHOOSING PUMP-AND-TREAT REMEDIATION

The first step in determining whether pump-and-treat is an appropriate remedial technology is to conduct a site characterization investigation. If the risk assessment shows the need for remedial action, then site characteristics, such as hydraulic conductivity, will determine the range of remedial options possible. Sources of ground-water contamination can include leaky tanks, leachate from landfills, spills, chemicals dissolving from nonaqueous phase liquids (NAPLs), and chemicals desorbing from the soil matrix.

Sites with ground-water contamination will almost always include some form of pump-and-treat remediation. Chemical properties of the site and plume need to be determined to characterize transport of the contaminant and evaluate the feasibility of a pump-and-treat system. To determine if pump-and-treat is appropriate at a given site, one needs to know the history of the contamination event, properties of the subsurface, ground-water flow characteristics, and biological and chemical contaminant characteristics. Identifying the chemical and physical site characteristics, locating the ground-water contaminant plume or NAPL in three dimensions, and determining aquifer and soil properties are necessary in designing an effective pump-and-treat strategy. Several remedial methods may be combined into a "treatment train" to attain cleanup goals. The criteria listed below outline the information necessary to determine if pump-and-treat systems are applicable to a site.

Criteria to Determine if Pump-and-Treat will be Effective

I) History of the contamination:

A history of the contamination event should be prepared to define the types of wastes present at the site and quantify their loading to the system.

II) Characteristics of the subsurface flow system:

Ground-water flow systems vary with time, season, and pumping strategy. Understanding where ground water recharges and discharges (mass balance), the laws governing flow (Darcy's law), and geologic framework through which the flow passes makes it possible to determine ground-water flow characteristics. Other subsurface flow system characteristics include hydraulic conductivity, storage coefficient, mineralogy, organic content, and aquifer thickness..

III) Chemical and biological characteristics of the contaminant:

Chemical characteristics of contaminants include solubility, density, reactivity, ion exchange capacity, and mobility in aqueous solution. Biological characteristics of contaminants include the potential for naturally occurring transformation and biodegradation.

PUMP-AND-TREAT REQUIREMENTS

Four basic components need to be developed for a successful pump-and-treat system.

- ❑ **Goals and objectives**
- ❑ **System design**
- ❑ **Operational rules and monitoring**
- ❑ **Termination criteria**

The first component consists of defining the remediation goals and objectives (remedial action objectives) to be accomplished at a given site. This involves gathering enough background site information and field data to make assessments of remedial requirements and possible cleanup levels. The first determination is whether cleanup or containment will be the most appropriate pump-and-treat remedial action. If cleanup is chosen, the level of cleanup must be determined according to maximum contaminant levels (MCLs) and alternate contaminant levels (ACLs), state laws, or other criteria selected for the site. If containment is chosen, pump-and-treat technology is used as a hydraulic barrier to prevent off-site migration of contaminant plumes. The goals and objectives chosen at this stage determine the course of the remediation plan.

The next component consists of the design and implementation of the pump-and-treat system based on data evaluated in setting the goals and objectives. The system must be chosen and designed based on field data. Selection of a system is also dependent on whether pump-and-treat is sufficient or more than one remedial action will be used. The criteria for well design, pumping system, and treatment are dependent on the physical site characteristics and contaminant type. The system may then be installed, including extraction wells, injection wells, drain intercepts, and barrier walls, if necessary.

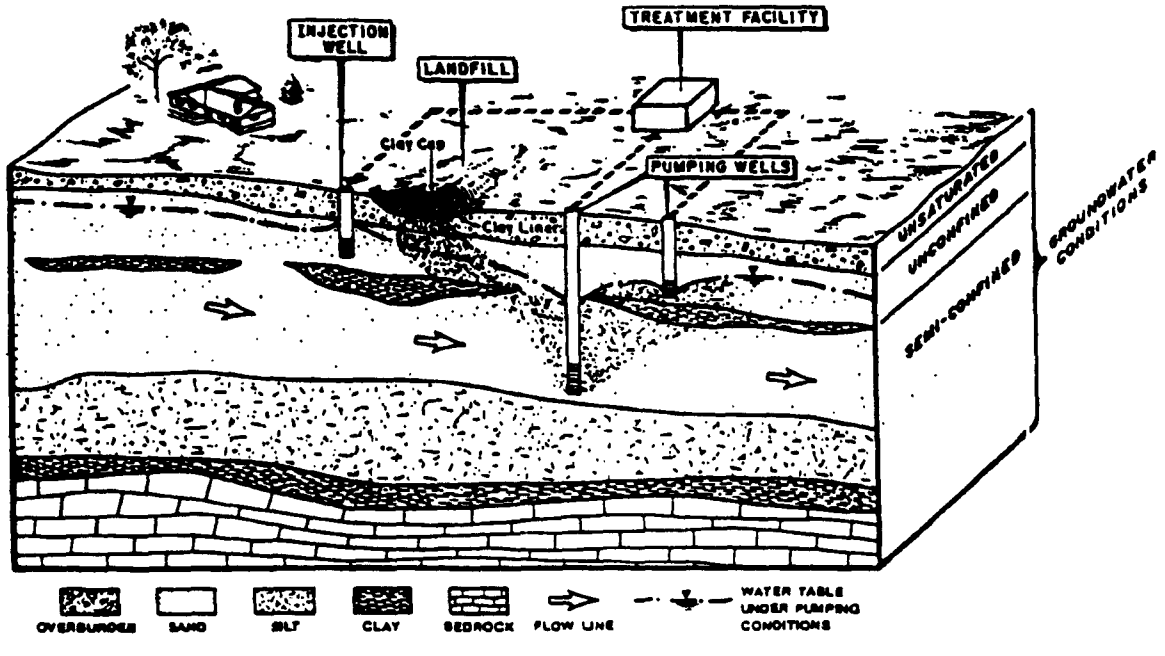
The third and most significant component for ensuring the long-term effectiveness of pump-and-treat is frequent monitoring of progress to verify if the remedial strategy is meeting remedial action objectives. Monitoring the remedial process with wells and piezometers allows the operator to make iterative adjustments to the system in response to changes in subsurface conditions caused by the remediation.

The final component in the pump-and-treat process is determining the termination requirements. Termination requirements are based on the cleanup objectives defined in the initial stage of the remedial process. The termination criteria are also dependent on the specific site aspects revealed during remedial operations.

DATA COLLECTION

Collecting as much background site data as possible initially may reduce the amount of time spent gathering data in the field. Accurate information on the type of contaminants present and their loading capacity will promote a well-designed remediation plan. Contaminant information needed consists of: 1) source characterization, including the volume released, the area infiltrated, and duration of release; 2) concentration distribution of contaminants and naturally occurring chemicals in ground water and soil; and 3) processes affecting plume development, such as chemical and biological reactions influencing contaminant mobility. Each step of the pump-and-treat strategy is dependent on the decisions reached in the previous step. Therefore, it is vital that each step is carefully planned and monitored to allow for modifications.

Example of a Pump-and-Treat System



Understanding the hydrogeology and extent of contamination at a site are important in planning successful field studies. The hydrogeologic aspects listed in Table 1 (below) are vital in determining if a pump-and-treat system would be an appropriate remedial technology for a particular site. These aspects include determining the size of the contaminated aquifer, depth to water table, hydraulic conductivity of surrounding aquifer material, and local ground-water use. Methods for determining aquifer properties include a slug test, pump test, and a borehole flowmeter test. The pump test consists of pumping one well and measuring the water level response of surrounding wells. Pump tests sample large aquifer sections. A slug test measures the rate at which the water level in one well returns to its initial state after inducing a rapid water level change by introducing or withdrawing a volume of water. The borehole flowmeter test measures flow direction and rate in a borehole. These tests can indicate the spatial variability of hydraulic conductivity.

Once data have been collected, the information must be accurately interpreted. There are numerous tools that can be used to interpret data, including geochemical analysis, geostatistical analysis, and mathematical models. Geochemical analysis uses ion speciation models to interpret chemical changes in the aquifer. Geostatistical methods may be used to determine the relationship among various parameters and define the statistical probability of a particular condition. Mathematical models may be used to simulate ground-water flow patterns, contaminant transport, and the changes resulting from a pump-and-treat system.

Water in a well bore seldom represents that of the adjacent aquifer. Therefore, when sampling ground water, pH, temperature, and conductivity should be measured and allowed to stabilize before a sample is taken to more accurately reflect the ground-water quality.

SYSTEM DESIGN

An effective pump-and-treat system depends on careful design of the pumping and treatment components based on the hydrogeologic information gathered at the site. Design considerations include type and location of wells, pumps, and piping; drilling methods; and well design and construction. Extraction wells may be used with injection wells if the hydraulic conductivity of the site material is high. Drains may be used if the contaminated aquifer is close to the surface. Intercept drains may be appropriate when a shallow aquifer is surrounded by material with low hydraulic conductivity. A long-term aquifer test (longer than a few days) can provide useful information and serve as a prototype for the pump-and-treat system design.

Table 1. Aspects of Site Hydrogeology

Geologic
1. Type, thickness, and areal extent of aquifer.
2. Type of porosity (primary: intergranular pore space, or secondary: bedrock).
3. Presence or absence of impermeable units and confining layers.
4. Depth to water table, thickness of vadose zone.

Hydraulic
1. Pressure conditions: confined, unconfined, or leaky confined.
2. Ground-water flow direction, hydraulic gradients, and average linear velocity.
3. Recharge and discharge area.
4. Ground-water and surface water interactions.
5. Seasonal variations of ground-water conditions.

Ground Water Use
1. Existing or potential underground sources of drinking water.
2. Existing or near-site use of ground water.

Special care is required to avoid potential problems with well-construction materials, especially when dealing with NAPLs. Wells should be designed so that screens may be easily flushed and clogging problems commonly caused by oxidation of manganese and iron can be treated. Aspects to consider when selecting pumps are failure rates, reactivity with contaminants, and ease of maintenance. Backup equipment should be available in the event of failure.

The types of pumping used at a site include continuous and pulsed pumping. Continuous pumping maintains an inward gradient, constantly drawing ground water towards it. Pulsed pumping consists of alternating periods of time when the pumps are on and when they are off.

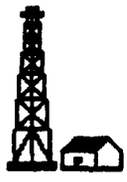
Depending on site characteristics and contaminant properties, injection wells may be installed along with extraction wells to reduce cleanup time. Injection wells increase the hydraulic gradient by flushing contaminants towards the extraction well.

The pump-and-treat system should be evaluated periodically to determine if the goals and standards of the design criteria are being met. Monitoring the remedial process allows for operational modifications to be made. One modification that may improve the efficiency of contaminant recovery is to switch from continuous to pulsed pumping. The non-pumping period during pulsed pumping allows the contaminants to diffuse and desorb from less permeable zones into adjacent zones of higher hydraulic conductivity, permitting more efficient contaminant extraction when pumping resumes.

Another design modification is to cycle pumping at selected wells in order to bring stagnant zones into active flow paths for remediation. When less soluble contaminants (NAPLs) are trapped in soil pores by interfacial tension, the flow rates during remediation may be too rapid for the contaminant to reach chemical equilibrium. The non-pumping stage at selected wells provides time for sorbed and residual contaminants in the stagnant zone to reach equilibrium with the ground water. Duration of pumping and non-pumping periods

are site-specific and can only be optimized through continuous monitoring.

Ideally, the contaminant source would be completely removed for proper aquifer remediation using pump-and-treat technology. Unremoved contaminants will continue to dissolve into the ground water and prolong cleanup. It may be advantageous to have multiple extraction wells pumping at a low rate rather than one at a high rate. Analytical and numerical modeling techniques can be used to evaluate alternative designs, optimal well spacings, pumping rates, and cleanup times. Models can calculate ground-water flow paths, locate contaminant plume fronts, and attempt to simulate contaminant transport. Proper design will ensure that wells are placed in the desired stratigraphic layer so that the correct area will be



OPERATION AND MONITORING

Once remedial action objectives are established and a system is built to meet these objectives, then a monitoring program should be designed to evaluate the success of the remedial system. Uncertainties in subsurface characterization make monitoring a necessary step in pursuing a remedial strategy. Continual monitoring of the pump-and-treat system allows timely modifications to be made when it is clear that the system is not achieving prescribed goals.

Monitoring should consist of analyzing the water quality and contaminant movement, and supervising the mechanical operation of the pump-and-treat system. If monitoring shows that the cleanup objectives are not being met, then changes to the pump-and-treat system must be specified and implemented to meet specified goals. There are three basic components involved in monitoring.

1) Design an appropriate monitoring program to suit the pump-and-treat system.

2) Actively monitor the system to verify that the remedial strategy is meeting the objectives and that equipment is functioning properly.

3) Modify the remedial strategy to adjust for unexpected contingencies. Specify alternate acceptable goals or change the remediation strategy to meet the original goals.

Monitoring criteria important in establishing a successful monitoring scheme for a site can be divided into three categories, chemical, hydrodynamic, and administrative.

- *Chemical:* A risk-based criterion, including maximum contaminant levels (MCLs), alternate contaminant levels (ACLs), detection limits, and natural water quality.

- *Hydrodynamic:* Includes preventing infiltration through the vadose zone, maintaining an inward gradient at the boundary of the contaminant plume, and providing minimum flow to surface water bodies.

- *Administrative Control:* Includes reporting requirements, frequency and character of operational and post-operational monitoring, and land use restrictions, such as drilling and other access-limiting restrictions.

The location of the monitoring wells is critical to any successful monitoring program. Water level fluctuations and water quality should be measured. Injection and extraction wells change the subsurface in complex ways, requiring continuous monitoring. Determining the flow pattern generated by a pump-and-treat system requires field evaluations during the operational phase.

A pump-and-treat system may require modifications during the operational phase due to the uncertainties involved in subsurface characterization. Reasons for possible modifications resulting from operational monitoring are:

- Improved estimates of hydraulic conductivity requiring a change in pumping rate or well location.

- Information on chemistry and loading to the treatment facility requiring changes in treatment.

- Mechanical failure of pumps, wells, or subsurface plumbing.

- Adjusting pumping rate or well location to remediate a stagnant zone (a hydrodynamically isolated zone) as the contaminant plume is remediated, or to enhance extraction if anticipated progress is not achieved.

SOLUTE TRANSPORT ASPECTS

Assessing the chemical properties of the contaminant plume is necessary to characterize the transport of the chemical and evaluate the feasibility of pump-and-treat. Movement of non-reactive dissolved contaminants in saturated media is controlled primarily by advection and somewhat by dispersion. Advection causes the plume to move at the rate and direction of ground-water flow. Properties that control the transport of chemicals in ground water should be considered when evaluating pump-and-treat systems.

Dispersion is the combined effect of mechanical mixing and chemical diffusion. Dispersion causes the plume volume to increase and its maximum concentration to decrease. Reactive contaminant transport is also affected by sorption, desorption, and chemical and biochemical reactions. Studying sorption-desorption and transformation processes is essential in understanding migration rates and concentration distributions of contaminants. The plume of a reactive contaminant tends to expand more slowly than that of a non-reactive contaminant, increasing cleanup time.

Necessary modifications resulting from the monitoring results should be implemented. The system design should be flexible enough to allow for easy adjustments to quicken cleanup. Keeping the possibility of modifications in mind when constructing the pump-and-treat system will promote the speed and efficiency of remediation.

The pump-and-treat system is terminated when the cleanup objectives are met. Monitoring is needed to ensure that desorption or dissolution of residuals does not cause an increase in the level of contamination after operation of the pump-and-treat system has ceased. Post-operational monitoring may be required for two to five years after termination depending on site conditions. Calculating the cleanup period for a site is necessary to estimate termination time and potential length of post-operational monitoring (See example on this page).

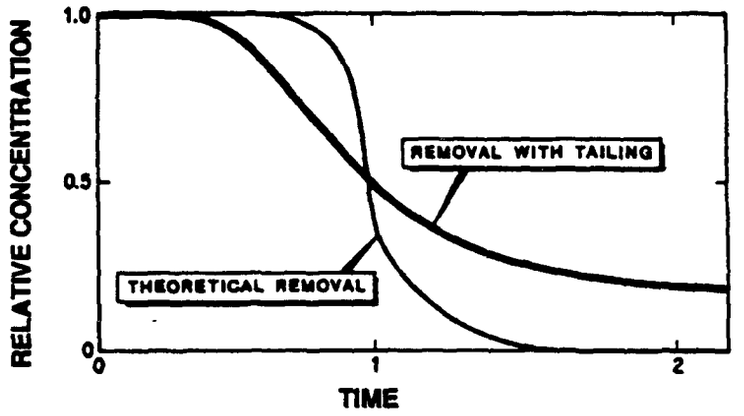
LIMITATIONS OF PUMP-AND-TREAT TECHNOLOGY

Reducing ground-water concentrations to standards required by the Safe Drinking Water Act or Land Disposal Restriction is difficult using available technology for many contaminants. There are several inherent limitations that hinder effective pump-and-treat site remediation. These include the potentially long time necessary to achieve the remediation goal; system designs failing to contain the contaminant as predicted, allowing the plume to migrate; and failure of surface equipment.

Research has substantiated other limitations with the use of pump-and-treat technology. These limitations include contaminant residual saturation, chemical sorption of the contaminant, and low hydraulic conductivity causing tailing effects.

1. ***Residual saturation***

The presence of nonaqueous phase liquids greatly complicates contaminant behavior. Movement of contaminants in a separate, immiscible phase is not well understood either in saturated or unsaturated zones. A less soluble contaminant moves in response to pressure gradients and gravity and is influenced by interfacial tension, volatilization, and dissolution.



Effects of tailing on pumping time

Residual saturation or irreducible saturation is the limit of drainage, where a certain pore volume will always remain. Both the type of immiscible fluid involved and the pore size distribution of the material determine the extent of residual saturation. Residual saturation reduces the overall amount of contaminant that enters and migrates within the saturated zone and acts as a source of long-term miscible contaminant.

Additional data required to determine proper remediation strategies for NAPLs include fluid specific gravity, viscosity, and contaminant thickness and distribution. Substances that are particularly difficult to remediate are halogenated aliphatic hydrocarbons, halogenated benzenes, phthalate ethers, and polychlorinated biphenyls. Data on relative permeability are readily available for many petroleum applications, but not for liquids usually found at hazardous waste sites.

2. ***Sorbed chemicals***

Mobile, non-reactive compounds are most effectively treated using pump-and-treat technology. Contaminants easily sorbed onto the soil matrix are more difficult to remediate effectively. The volume of

AN EXAMPLE OF CALCULATING CLEANUP TIMES

Assume that the area of ground-water contamination is ten acres; the aquifer is permeable and 55 feet thick; water in storage is 30% of the aquifer's volume; and the water is contaminated with a nonreactive substance. Under these conditions it would be possible to exchange one pore volume of water in this ten acre plume in about a year with a pumping rate of 100 gallons/minute.

Volume of contaminant = 10 acres x 43,560 ft^2 / acre x 55 ft. x 7.48 gal/ft^3 x 0.3 = 5.4 x 10^6 gallons.

The pumping rate to remove this volume in one year = 5.4 x 10^6 gallons/365 days/1440 min./day = 102 gallons per minute. However, it will take longer than one year to completely remediate the contaminant due to the tailing effect often observed when using pump-and-treat technology. Tailing is the asymptotic decrease of contaminant concentrations in water removed in the cleanup process. Several phenomena may cause tailing, including the presence of a highly soluble and mobile contaminant that migrates into less permeable zones of the geologic material, a reactive, easily sorbed compound, and desorption. Sites with tailing effects require longer pumping times and greater pumping volumes to reach the same level of remediation.

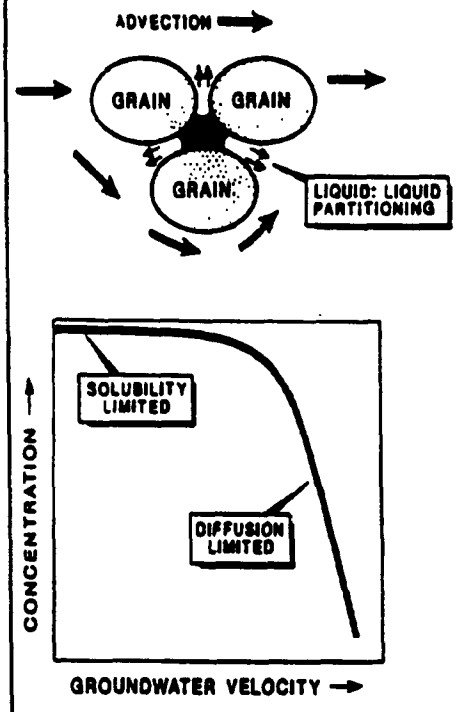
pumped water required to remove the contaminant depends on the sorption capacity, the geologic material through which it flows, and the ground-water flow velocity during remediation.

If the ground-water flow velocity induced by pumping is too rapid, the contaminant concentration levels will not reach equilibrium. This results in decreased efficiency of contaminant removal (See diagram on the right). The retardation factor of a chemical (contaminant velocity relative to the water velocity) can be determined to estimate potential sorption capacity and remediation time.

3. *Hydraulic conductivity*

Hydraulic conductivity is another factor influencing the effectiveness of pump-and-treat remediation. Favorable conditions for pump-and-treat activities are high hydraulic conductivity—greater than 10^{-3} cm/sec—and homogeneity of the surrounding aquifer material. Determining pump-and-treat feasibility is specific to a site. The same range of hydraulic conductivities may allow a pump-and-treat system to be applied at one site but not at another depending on physical site characteristics and chemical properties of the contaminant.

These limitations are not insurmountable if accurate data collection and careful planning are employed when designing and operating a pump-and-treat system.



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U.S. Environmental Protection Agency, 1987b. MINTEQA1; an equilibrium metal speciation model: user's manual, EPA/600/3-87/012, Athens, Georgia.

U.S. Environmental Protection Agency, 1988b. Guidance on remedial actions for contaminated ground water at Superfund sites. EPA/540/G-88/003, Cincinnati, Ohio.

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U.S. Environmental Protection Agency, 1990. Emerging Technology Report - Removal and Recovery of Metal Ions from Ground Water, EPA/540/5-90/005a (Evaluation Report, EPA/540/5-90/005b (Data and Supporting Information)).

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U.S. Environmental Protection Agency, 1990. Handbook: Ground Water, Volume 1: Ground water and contamination. USEPA Center for Environmental Research Information, Cincinnati, OH, EPA/625/6-90/016a, 144 p. Contains discussions of site investigations leading to aquifer restoration techniques.

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United States Environmental Protection Agency | Office of Solid Waste and Emergency Response | Office of Research and Development | 9380.1-03AFS May 1991

EPA

Superfund Innovative Technology Evaluation Program

SITE Program Fact Sheet

SITE PROGRAM OVERVIEW

The Superfund Innovative Technology Evaluation (SITE) program supports development of technologies for assessing and treating waste from Superfund sites. The SITE program was authorized by the Superfund Amendments and Reauthorization Act of 1986 with the goal of identifying technologies, other than land disposal, that are suitable for treating Superfund wastes. The program provides an opportunity for technology developers to demonstrate their technologies' capability to successfully process and remediate Superfund waste. EPA evaluates the technology and provides an assessment of potential for future use for Superfund cleanup actions. The SITE program has currently evaluated and/or supported RD and D efforts for more than 100 innovative treatment technologies. The SITE program is administered by EPA's Risk Reduction Engineering Laboratory (RREL) in Cincinnati, Ohio.

This fact sheet describes the four components of the SITE Program with particular emphasis on the Demonstration Program, which conducts evaluation demonstrations of operating alternative technologies. This page of the fact sheet summarizes the overall SITE Program. Subsequent pages provide additional detail about each program component. This fact sheet also contains a list of contacts for further information, and an order form for technology transfer publications and videos.

COMPONENTS OF THE SITE PROGRAM

The SITE program integrates four related components, the Demonstration Program, the Emerging Technologies Program, the Measurement and Monitoring Technologies Program, and the Technology Transfer Program.

DEMONSTRATION PROGRAM

The Demonstration Program provides engineering, cost, reliability, and applicability data on new Superfund remediation technologies by sponsoring field demonstrations of pilot or full-scale technologies. Technology developers demonstrate their methods on selected wastes, and EPA analyzes, evaluates and disseminates the test results. Typically, no funding is made available to the developer during this process. Figure 1 illustrates the categories of technologies currently enrolled in the Demonstration Program.

Innovative Technologies Program

This supplement to the Demonstration Program was established to encourage private sector development and commercialization of EPA-developed hazardous waste treatment technologies for use at Superfund sites. The Federal Technology Transfer Act of 1986 authorized the EPA/industry partnership that is necessary to bring these technologies to commercialization. This will enable EPA laboratories to collaborate with industry, thus facilitating development of the technologies and reducing the market risk.

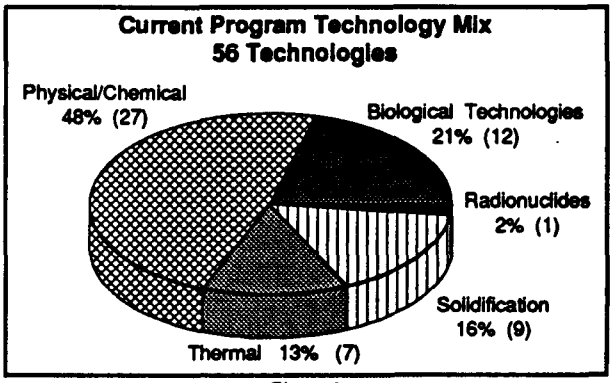


Figure 1

EMERGING TECHNOLOGIES PROGRAM

The Emerging Technologies Program (ETP) supports the development of new, innovative technologies by following laboratory and bench-scale technologies through pilot-scale testing. The ETP provides up to two years of financial assistance to private developers for technology research and development through cooperative agreements.

MEASUREMENT AND MONITORING TECHNOLOGIES PROGRAM

The Measurement and Monitoring Technologies Program (MMTP) is designed to improve the accuracy of Superfund site characterization efforts. The MMTP tests the ability of advanced technologies to assess the nature and extent of contamination, and evaluate cleanup levels. Funding is generally not provided to developers under this program.

TECHNOLOGY TRANSFER

The Technology Transfer portion of the SITE program disseminates information from the other three programs to increase awareness and use of alternative technologies for assessing and remediating Superfund sites. Technology transfer occurs through reports, brochures, videos, seminars, public meetings and site visits, conference exhibits, and technical support to EPA Regions, States, and Superfund contractors.

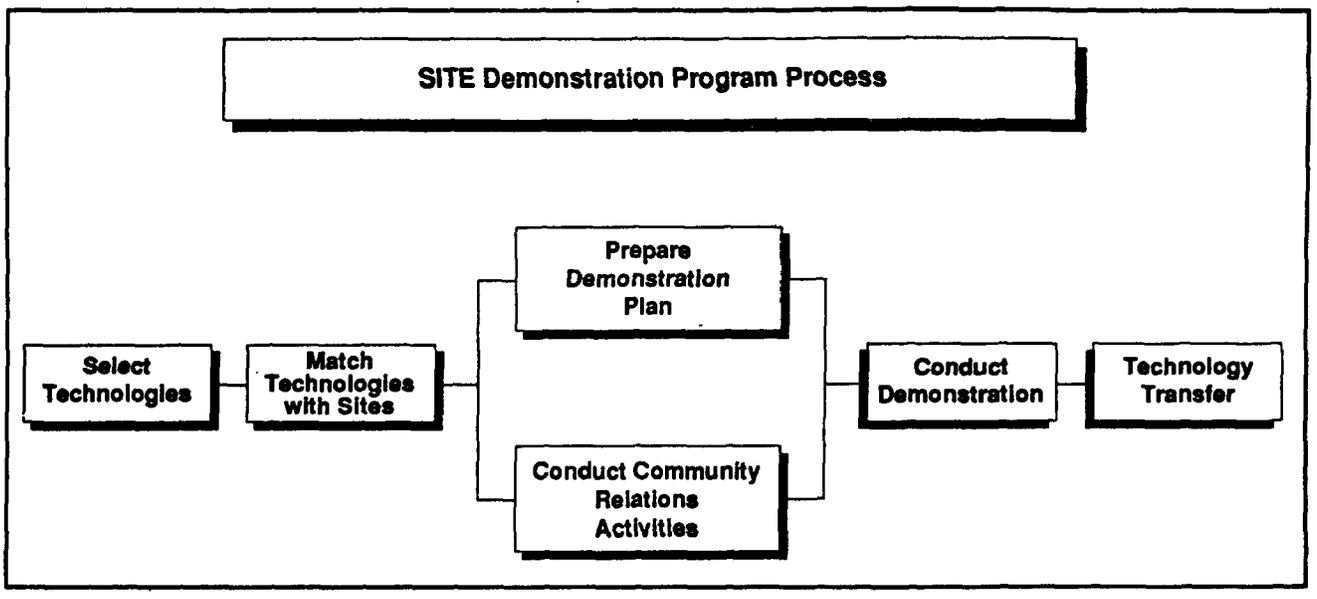


Figure 2

DEMONSTRATION PROGRAM PROCESS

The Demonstration Program selects technologies and conducts field demonstrations through the process illustrated in Figure 2. Each step in the process is discussed below.

Select Technologies: In January of each year EPA solicits applications for the demonstration program. Developers submit proposals which are reviewed and accepted by EPA.

Match Technologies with Site: EPA and the developer select a site for the demonstration based on several considerations: the developer's waste and location preferences, relevance of the technology to the site cleanup, and Regional needs. EPA meets with Regional and State representatives, the developer and other interested parties to visit sites prior to making a final selection.

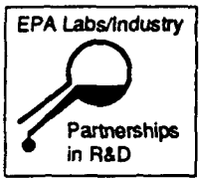
Prepare Demonstration Plan: EPA develops a Demonstration Plan that details how to sample waste for testing, prepare the selected site for the demonstration, dispose of residual materials, and evaluate the technology in the field. Both EPA and the technology developer must approve the Demonstration Plan.

Conduct Community Relations Activities: In most cases, opportunity for public comment is required prior to the actual demonstration. EPA prepares fact sheets on the demonstration, designates a period for the public to comment, and may hold local public meetings and/or land site visits.

Conduct Demonstrations: The demonstration of the selected technology can last from a few days to several months. The technology developer is financially responsible for mobilizing and operating the technology. EPA prepares the site, provides utilities, collects samples, performs QA field and laboratory audits, and evaluates the results. EPA also handles the logistical arrangements for a Visitor's Day where the Regional and State officials, the public and interested professionals are invited to view the demonstration.

Conduct Technology Transfer: After the demonstration, EPA prepares an Applications Analysis Report that assesses the overall applicability of the technology to other sites and wastes, and includes technology cost, performance, and reliability information. In addition, EPA prepares a Technology Evaluation Report which presents a summary of the demonstration and evaluation results. Contact John Martin at 513-569-7758 for further information.

Innovative Technologies Program



Through cooperative research and development agreements (CRDAs), EPA laboratories will work closely with industry to develop and commercialize on-site destruction and hazardous waste cleanup technologies. Through the program, EPA is involved in the development of a variety of technologies. Examples include:

- Mobile Debris Washer;
- Base Catalytic Destruction System (BCD - APEG - KPEG);
- Volume Reduction Unit (VRU); and
- Excavation Technique and Foam Suppression Methods.

For further information on this program, contact Steve James at (513) 569-7877.

EMERGING TECHNOLOGIES PROGRAM (ETP) HIGHLIGHTS

The Emerging Technologies Program is supporting 30 technologies and is currently planning to fund 13 projects from the 1990 solicitation. Solicitation for preproposals occurs in July of each year, the selected developers are then invited to submit a Cooperative Agreement Application for review. Final selection of projects is made in March of each year.

This is a co-funding effort between the developer and EPA, with EPA funding up to $150,000 each year. Funding for the second year is determined by the progress of the first year's research. Funding support for the program has also been received from the Department of Energy, and the Department of Defense (Air Force).

Several projects completed from the first year solicitation are being invited into the Demonstration Program. Program emphasis is being placed on innovative processes, that may be capable of field scale efforts in the second year of research. This provides a stronger basis for moving into the Demonstration Program. Contact Norma Lewis at 513/569-7758 for further information.

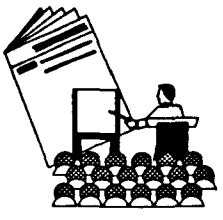
MEASUREMENT AND MONITORING TECHNOLOGIES PROGRAM OBJECTIVES

The Measurement and Monitoring Technologies Program, based at EPA's Environmental Monitoring System Laboratory in Las Vegas, Nevada, sponsors research on advanced Superfund site assessment technologies. MMTP objectives include:

- Identifying existing technologies that can enhance field monitoring and site characterization;
- Supporting development of monitoring capabilities that cannot be cost-effectively addressed with current technology;
- Demonstrating those technologies that emerge from the screening and development phases of the program; and
- Preparing protocols, guidelines and standard operating procedures for new methods.

For further information on MMTP, please contact Eric Koglin, FTS 545-2432 or (702) 798-2432.

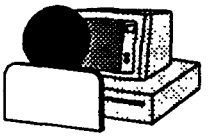
TECHNOLOGY TRANSFER ACTIVITIES



Technical information gathered through all of the SITE programs is exchanged through a variety of activities. Data results and status updates are disseminated to increase awareness of alternative technologies available for use at Superfund sites. A wide array of media are utilized to reach decision makers involved in Superfund sites including:

- SITE brochures, publications, reports, videos and fact sheets;
- Pre-proposal conferences on SITE solicitations;
- Public meetings and on-site visitors' days;
- Seminar series;
- SITE exhibit displayed at nationwide conferences;
- Innovative technologies program exhibition;
- Networking through forums, professional associations, centers of excellence, regions, and states; and
- Journal articles.

Alternative Treatment Technology Information Center (ATTIC)



The Alternative Treatment Technology Information Center (ATTIC) is an information retrieval network that can provide up-to-date technical information on innovative treatment methods for hazardous wastes. Information available through the ATTIC database includes abstracts and executive summaries from over 1200 technical documents and reports. These abstracts and summaries, delineated by technology, are categorized into five groups: (1) Thermal Treatment; (2) Biological Treatment; (3) Solidification/Stablilzation Processes; (4) Chemical Treatment; and (5) Physical Treatment. The Attic Database provides the user with access to innovative technology demonstration studies, a variety of treatability, cost analysis models, migration and sampling databases, underground storage tank case histories and remediation ideas. The ATTIC network can also enable access to expert assistance, a calender of events, and a list of publications.

ATTIC can be accessed through an online system, a system operator or through a disk-based version. For assistance and/or information call the ATTIC operator at 301-816-9135.

SITE PROGRAM CONTACTS

ORD/RREL Contacts:

Demo Program	John Martin FTS 684-7758 513-569-7758	Emerging Program	Norma Lewis FTS 684-7665 513-569-7665

Regional Contacts:

REGION	NAME	REGION	NAME
1	Diana King FTS 833-1676 617-573-9676	6	Don Williams FTS 255-2197 214-655-2197
2	Peter Moss FTS 264-4703 212-264-4703	7	Dana Trugley FTS 276-7705 913-551-7705
3	Paul Leonard FTS 597-8485 215-597-8485	8	Gerald Snyder FTS 330-7504 303-294-7405
4	John Risher FTS 347-1586 404-347-1586	9	John Blevins FTS 484-2241 415-744-2241
5	Steve Ostrodka FTS 886-3011 312-886-3011	10	John Barich FTS 399-8562 206-533-8562

Headquarters Contacts:

OSWER /TIO	John Quander FTS 398-8845 703-308-8845	ORD/ OEETD	Richard Nalesnik FTS 382-2583 202-382-2583

SITE DEMONSTRATION PROGRAM ACCOMPLISHMENTS

The Agency has successfully completed 20 field technology demonstrations at Superfund sites as indicated in Table 1. In addition, four measurement and monitoring technologies have been field demonstrated. SITE project results may be obtained by contacting the EPA Center for Environmental Research Information (CERI) at (513) 569-7562 or FTS 684-7562.

Table 1

Completed Field Demonstrations

	REGION SITE/ DEVELOPER	DESCRIPTION	PROJECT MANAGER
I	Groveland Wells, MA; Terra Vac. Inc.	In-Situ vacuum extraction of VOCs in soil	Mary Stinson FTS: 340-6683 201-321-6683
II	New Bedford Harbor, MA; CF Systems Corp.	Solvent Extraction to Remove PCBs from sediments	Laurel Staley FTS: 684-7863 513-569-7863
	Imperial Oil, NJ; Soliditech, Inc.	Solidification/ stabilzation of heavy metals and organics	Walter Grube FTS: 684-7798 513-569-7798
III	Douglassville, PA; Hazcon, Inc. (IM-TECH)	Solidification/ stabilization of volatile and semi-volatiles, organics, PCBs, and heavy metals	Paul dePercin FTS: 684-7797 513-569-7797
	Palmerton, PA; E.I. DuPont DeNemours & Co.	Membrane Microfiltration	John Martin FTS: 684-7758 513-569-7758
	Monaca, PA; Horsehead Resource Development Co.	Flame Reactor	Donald Oberacker FTS: 684-7510 513-569-7510
IV	G.E. Hialeah, FL; International Waste Technology	In-situ solidification of PCBs	Mary Stinson FTS: 340-6683 201-321-6683
	Peak Oil, FL; Shirco Infrared System, Inc.	Transportable IR thermal processing systems for treatment of PCBs, organics, lead, and other metals in soil and sludge material	Howard Wall FTS: 684-7691 513-569-7691
	Risk Reduction Engineering Lab, Cincinnati, OH (Kentucky and Georgia locations)	Debris Washing System	Naomi Barkley FTS: 684-7854 513-569-7854
V	Rose Township, MI; Shirco IR Systems, Inc.	Infrared Incinerator System	Howard Wall FTS: 684-7691 513-569-7691
	McGillis & Gibbs, MN; Biotrol	Soil washing	Mary Stinson FTS: 340-6683 201-321-6683
	McGillis & Gibbs, MN; Biotrol	Biotreatment of groundwater	Mary Stinson FTS: 340-6683 201-321-6683
VI	EPA's Combustion Research Facility, AR; American Combustion Technologies, Inc.	Pyretron oxygen and airburner for use with a rotary kiln incinerator	Laurel Staley FTS: 684-7863 513-569-7863
IX	Lorentz Barrel and Drum, CA; Ultrox International, Inc.	UV/ozone oxidation of orgainc in groundwater	Norma Lewis FTS: 684-7665 513-569-7665
	McColl Site Fullerton, CA; Excavation Techniques	Excavation & Foam Suppression of Volatiles	Jack Hubbard FTS: 684-7507 513-569-7507
	Lockheed Site Burbank, CA; AWD Technologies, Inc.	Integrated In-Situ Vapor Extraction & Steam Vacuum Stripping Process	Gordon Evans FTS: 684-7684
	McColl Site, CA; Ogden Environmental Services	Circulating fluidized bed combustor	Douglas Grosse FTS: 684-7844 513-569-7844
	Annex Terminal, San Pedro, CA; Toxic Treatments, Inc.	In-situ steam - airstripping of volatile organics in soil	Paul DePercin FTS: 684-7797 513-569-7797
	Selma Site, Fresno, CA; Silicate Technology Corp.	Silicate Compounds by Solidification/ Stabilization	Edward Bates FTS: 684-7774 513-569-7774
X	Portable Equipment Company, OR; Chemfix Technologies, Inc.	Chemical fixation/ stabilization of organics and inorganics in waste slurries	Ed Barth FTS: 684-7669 513-569-7669

SITE PROGRAM DOCUMENTS

The following SITE demonstration project publications are available from EPA. Indicate your choice by checking the appropriate box(es) on the order form below. The form may be copied.*

General Publications

☐ Technology Profiles (EPA/540/5-90/006)

Project Results

American Combustion - Oxygen Enhanced Incineration

☐ Technology Evaluation (EPA/540/5-89/008)

☐ Applications Analysis (EPA/540/A5-89/008)

CF Systems Corp. - Solvent Extraction

☐ Technology Evaluation (EPA/540/5-90/002)

☐ Applications Analysis (EPA/540/A5-90/002)

Chemfix Technologies, Inc. - Chemical Fixation/Stabilization

☐ Technology Evaluation (EPA/540/5-89/011)

☐ Applications Analysis (EPA/540/A5-89/011)

Hazcon - Solidification

☐ Technology Evaluation (EPA/540/5-89/001a)

☐ Applications Analysis (EPA/540/A5-89/001)

IWT In-Situ Stabilization

☐ Technology Evaluation (EPA/540/5-89/004a)

☐ Applications Analysis (EPA/540/A5-89/004)

Shirco-Infrared Incineration

☐ Technology Evaluation - Peak Oil (EPA/540/5-88/002a)

☐ Technology Evaluation - Rose Township (EPA/540/5-89/007a)

☐ Applications Analysis (EPA/540/A5-89/007)

Soliditech, Inc. - Solidification

☐ Technology Evaluation (EPA/540/5-89/005a)

☐ Applications Analysis (EPA/540/A5-90/005)

Terra Vac - Vacuum Extraction

☐ Technology Evaluation (EPA/540/5-89/003a)

☐ Applications Analysis (EPA/540/A5-89/003)

Ultrox International - Ultraviolet Ozone Treatment for Liquids

☐ Technology Evaluation (EPA/540/5-89/012)

☐ Applications Analysis (EPA/540/A5-89/012)

☐ Check here if you would like your name placed on the SITE mailing list

Your Name and Mailing Address (please print)

MAIL TO: **ORD Publications**
26 W. Martin Luther King Drive (G72),
Cincinnati, Ohio 45268

* Documents ordered through ORD Publications are free of charge.

SITE VIDEOCASSETTES

SITE Program videos are also available on selected sites for a small fee. These videos contain footage of actual field demonstration activities, including Visitor Day programs. For further information contact Marilyn Avery, Foster Wheeler Enviresponse, Inc., 8 Peach Tree Hill Rd., Livingston, N.J. 07039, Phone: 908-906-6860.

The SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION (SITE) Program understands the problems associated with a cleanup activity and can provide solutions, service, and support for these problems. EPA's Risk Reduction Engineering Laboratory (RREL) developed this brochure to define the SITE Program capabilities and resources available to EPA's Regional Offices.

THE SITE ADVANTAGES

SITE, short for Superfund Innovative Technology Evaluation, is a unique, international program dedicated to promoting the development and commercialization of innovative treatment technologies for use at hazardous waste sites. The program involves evaluations with technology developers to determine the effectiveness of their innovative technologies. Effectiveness is judged in terms of performance objectives and costs.

The Demonstration Program, one of four components in SITE, offers definite advantages to meet Regional needs. The SITE Demonstration Program provides:

- Expert assistance to the Remedial Project Manager and On-Scene Coordinator (RPM and OSC) in judging the applicability of an innovative technology for a particular site waste
- A field demonstration, and/or a treatability study, that supports innovative technology selection in a Remedial Investigation/ Feasibility Study (RI/FS)
- Cost sharing of a demonstration or treatability study with the technology developer
- A technology test plan tailored to meet Regional information needs
- An evaluation of the technology's effectiveness and reliability, plus information for cost comparisons
- Overall assistance and resources for SITE community relations activities
- A responsive turn-around of cost and performance data for RPMs and OSCs
- An option for planned waste removals requiring off-site treatment and evaluation
- EPA's Testing and Evaluation facility or a developer's facility that accepts wastes shipped off-site for destruction or treatment

HOW SITE CAN HELP YOU

With information . . .

SITE recognizes that timely, relevant information is imperative for RPMs and OSCs to evaluate and justify cleanup alternatives. SITE's advancement of innovative technologies is not only beneficial but is crucial to the future of the Superfund Program because it provides additional cleanup options. Under SITE, many promising technologies are now being evaluated for destroying or reducing the toxicity, mobility, or volume of hazardous waste.

With tailored demonstrations . . .

SITE emphasizes flexibility--it will tailor demonstrations and treatability studies to accommodate Regional needs and time requirements. SITE can generate useful data tailored to meet the RPMs and OSCs site-specific objectives. The Program can easily be integrated into the remedial process (**Figure 1**) or become a strategic part of a planned removal action. The earlier SITE is involved, the more support it can provide.

With ongoing projects . . .

A technology does not need to be in the SITE Program to be evaluated under SITE. Any innovative technology that the Region is planning or using for a cleanup operation can be evaluated by the SITE Program. The Regions gain high quality, credible data, with SITE responsible for the sampling, analysis, and evaluation.

The *SITE* process can be incorporated at any stage in the Superfund process

SITE PROCESS	SUPERFUND PROCESS	*SITE* PRODUCTS
	PA/SI	
Waste/Site Characterization Site Screening	⇩	Treatability Study Test Plan
	RI	
Treatability Study Technology/Site Matching Community Relations/ Permitting Assistance	⇩	Treatability Study Data and Report Technology Fact Sheet
	FS	
Technology Demonstration Planning - Phase 1 Field Demonstration - Phase 2	⇩	Technology Demonstration Plan Site Preparation Equipment Shakedown Sampling/Analysis Equipment Demobilization
	ROD	
Data Information Feedback	⇩	Early debriefing of laboratory results Publish demonstration bulletin Publish reports – Applications Analysis Technology Evaluation
Long-term Monitoring *(if applicable)*	RD/RA	Follow-up Evaluation Report Technical/Cost-Effectiveness Study *(when technology is selected for cleanup)*

Figure 1. Conceptualization of *SITE* Integration Process

Through solutions, service, and support . . .

Solutions--SITE speeds up decision-making by providing additional data that can assist in evaluating and justifying remedies in the Record of Decision (ROD).

Service--SITE evaluates demonstrations and treatability studies involving innovative treatment technologies. These evaluations provide focused, quality assured, site-specific cost and performance data.

SITE also publishes and distributes technology evaluation results through technical reports, bulletins, summaries, and other technology transfer activities.

Support--SITE provides the Regions with technical personnel in specific technology areas, and direct access to technical experts for problem-solving.

REGIONAL PARTICIPATION

The success of the Superfund Program relies on a team approach. Integration of all participants in the remediation process is essential to make innovative treatment technologies more available in the marketplace.

SITE's objective is to support the Regions by providing innovative treatment technology options for site remediation and removal activities. Involvement in the SITE Program is a Regional decision, and the degree of personal participation is flexible.

The SITE Program needs your support for matching innovative technologies with sites. A combined effort between the Regions and the SITE Program will assist in identifying sites to host demonstrations. This can be accomplished in one of several ways.

- SITE publishes lists of innovative technologies needing a site match (see insert), and Regions nominate candidate sites.
- SITE supports ongoing (or planned) activities. RPMs and OSCs conduct or plan an innovative technology demonstration or field treatability study at their site and want SITE to evaluate the technology. The SITE Program provides sampling and analytical support and overall technical assistance for the evaluation.
- Regions propose problem sites. In cooperation with the Superfund Technical Assistance Response Team (START), SITE provides solutions through annual solicitations of innovative technologies and through direct contact with developers.

With collective effort, the SITE Program will continue to expand and provide much needed data on innovative technologies.

Regional knowledge of and accessibility to the SITE Program boost its potential. To increase awareness and facilitate communication in the Regions, the RREL has established SITE contacts for each Region.

SITE REGIONAL CONTACTS

SITE Program Contact/Phone	*SITE Regional Coordinator Contact/Phone*
Region 1	
Kim Kreiton FTS 684-7328 513/569-7328	Dana King FTS 835-1556 617/573-1556
Region 2	
Ron Lewis FTS 684-7856 513/569-7856	Peter Moss FTS 264-4703 212/264-4703
Region 3	
Paul dePercin FTS/684-7797 513/569-7797	Paul Leonard FTS 597-8485 215/597-8485
Region 4	
Teri Shearer FTS 684-7949 513/569-7949	John Risher FTS 347-1586 404/347-1586
Region 5	
Laurel Staley FTS 684-7863 513/569-7863	Steve Ostrodka FTS 886-3011 312/886-3011
Region 6	
Randy Parker FTS 684-7271 513/569-7271	Don Williams FTS 255-2197 214/665-2197
Region 7	
Doug Grosse FTS 684-7341 513/569-7341	Dana Trugley FTS 276-7705 913/551-7705
Region 8	
Annette Gatchett FTS 684-7697 513/569-7697	Gerald Snyder FTS 330-7504 303/294-7504
Region 9	
Jack Hubbard FTS 684-7507 513/569-7507	John Blevins FTS 484-2241 415/744-2241
Region 10	
Norma Lewis FTS 684-7665 513/569-7665	John Barich FTS 399-8562 206/553-8562

ADDITIONAL SITE PROGRAM COMPONENTS

The advantages of the other SITE component programs are:

The Emerging Technologies Program

- Provides a framework to support development of new, innovative technologies by tracking laboratory, bench- and pilot-scale technologies through the scale-up process
- Compares the waste applicability of particular technologies to Superfund site waste characteristics
- May produce promising technologies that can be evaluated in the field

The Monitoring and Measurement Technologies Program

- Improves the accuracy of field characterization
- Provides RPMs and OSCs with a means to identify and demonstrate existing monitoring and measurement technologies
- Provides options that may be less expensive, more effective, and faster than current technologies for detecting contaminants at hazardous waste sites

The Technology Information Services

- Distributes quality data on innovative treatment technologies
- Establishes a public outreach and communication network that provides up-to-date technical information
- Addresses "bottom line" issues with performance and cost information

RREL participates in an established network of technical assistance programs to support the Regions in their selection and evaluation of cleanup technologies. Vital programs in this network are SITE, START, and the Engineering Forum. The activities in these programs complement each other; in fact, most START team leaders are also SITE project managers. Also, additional information on the application of innovative treatment technologies is accessible through OSWER's Technology Innovation Office.

EPA
The SITE Program
U.S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268

INSIDE: *SITE* Program Advantages

SITE
SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

EPA

TECHNOLOGIES AVAILABLE FOR DEMONSTRATION

The technologies listed below are available for demonstration at compatible sites. To receive additional technology information, check the appropriate boxes below, then fold and mail this form (see other side) to John Martin, RREL, in Cincinnati, Ohio.

CONTAMINANTS	WASTE MEDIA	DEVELOPER	TECHNOLOGY	SEND INFO
Volatile and nonvolatile hydrocarbons	Soil	BioVersal USA, Inc.	BioGenesis process for extraction of hydrocarbons	☐
Pesticides, oil, grease, heavy metals	Sludge, wastewater, leachable soil	EPOC Water, Inc.	Precipitation and microfiltration, and sludge dewatering	☐
Cyanide, organic compounds	Groundwater, wastewater, leachate	Exxon Chemical, Inc./Rio Linda Chemical Co.	Chemical oxidation/ cyanide destruction	☐
Biodegradable organics	Soil, sludge	In-Situ Fixation Co.	In-situ bioremediation	☐
Biodegradable organics	Soil	International Environmental Technology/YWC Midwest	Geolock/bio-drain treatment	☐
Volatile and semivolatile organics, PCBs, pesticides	Soil, sludge, sediment	Recycling Sciences International, Inc.	Low-temperature thermal desorption	☐
Halogenated and nonhalogenated organics, pesticides	Soil, sludge, liquid waste	Remediation Technologies, Inc.	Liquid/solid contact digestion	☐
Nonspecific organics, oily wastes	Soil, sludge	Resources Conservation Co.	Solvent extraction (BEST process)	☐
Metals, semivolatile organics	Soil	S.M.W. Seiko, Inc.	In-situ solidification/ stabilization	☐
Acidic sludges with >5% hydrocarbons, low-level metals	Sludge	Separation and Recovery Systems, Inc.	Solidification/ stabilization	☐
Heavy metals	Aqueous solutions	Techtran, Inc.	Chemical binding and physical separation	☐
Petroleum sludge	Sludge	Thermal Waste Management	Production of fossil fuel	☐
Biodegradable organics	Groundwater, industrial wastewater, leachate	Zimpro/Passavant, Inc.	Powdered activated carbon and biological treatment (PACT)	☐

Please complete if you are interested in receiving additional information on the above SITE technologies.

Name _____ U.S. EPA Region _____

Street _____

City _____ State _____

Zip _____ FTS: _____

Please identify specific sites for evaluating the technologies listed above or for future technology evaluations.

_____

The SITE Program
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
26 West Martin Luther King Drive
Cincinnati, OH 45268

John Martin
Chief, Demonstration Section
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
26 West Martin Luther King Drive
Cincinnati, OH 45268

COMPLETED SITE DEMONSTRATIONS AS OF NOVEMBER 1990

DEVELOPER	TECHNOLOGY	SITE LOCATION	VISITOR'S DAY	TECHNOLOGY EVALUATION REPORT	APPLICATIONS ANALYSIS REPORT	REGIONAL CONTACT	PROFILE PAGE NO.
AWD Technologies Inc. San Francisco, CA (September 1990)	Integrated Vapor Extraction and Steam Vacuum Stripping	San Fernando Valley Ground-Water Basin Superfund Site in Burbank, CA	September 20, 1990	In preparation	In preparation	Alisa Greene EPA ORD 415/744-1890	22
Excavation Techniques – Not Specific to a Developer (June and July 1990)	Excavation Techniques and Foam Suppression	McColl Superfund Site in Fullerton, CA	Not applicable	In preparation	In preparation	S. Jackson Hubbard EPA ORD 513/569-7507	46
E.I. DuPont de Nemours and Co., Newark, DE/ Oberlin Filter Co., Waukesha, WI (April 1990)	Membrane Microfiltration	Palmerton Zinc Superfund Site in Palmerton, PA	April 10, 1990	In preparation	In preparation	Tony Koller EPA Region III 215/597-6906	38
Risk Reduction Engineering Lab (December 1989)	Debris Washing	Superfund Sites in Detroit, MI; Hopkinsville, KY; and Walker County, GA	Not applicable	In preparation	In preparation	Naomi Barkley EPA ORD 513/569-7854	76
BioTrol, Inc., Chaska, MN (September 1989)	Soil Washing	MacGillis & Gibbs Superfund Site in New Brighton, MN	September 27, 1989	In preparation	In preparation	Rhonda McBride EPA Region V 312/886-7242	26
Toxic Treatment USA (September 1989)	In-Situ Steam/Air Stripping	Annex Terminal, San Pedro, CA	September 7, 1989	In preparation	In preparation	Paul dePercin EPA ORD 513/569-7797	96
BioTrol, Inc., Chaska, MN (July 1989)	Biological Aqueous Treatment	MacGillis & Gibbs Superfund Site in New Brighton, MN	September 27, 1989	In preparation	In preparation	Rhonda McBride EPA Region V 312/886-7242	24

COMPLETED SITE DEMONSTRATIONS AS OF NOVEMBER 1990

DEVELOPER	TECHNOLOGY	SITE LOCATION	VISITOR'S DAY	TECHNOLOGY EVALUATION REPORT	APPLICATIONS ANALYSIS REPORT	REGIONAL CONTACT	PROFILE PAGE NO.
Ogden Environmental Services San Diego, CA (March 1989)	Circulating Fluidized Bed Combuster	Ogden's Facility in La Jolla, CA	Not applicable	In preparation	Not applicable	John Blevins EPA Region IX 415/744-2241	64
Chemfix Technologies, Inc. Metairie, LA (March 1989)	Chemical Fixation/ Stabilization	Portland Equipment Salvage Company in Clackamas, OR	March 15, 1989	In preparation	In preparation	John Sainsburg EPA Region X 206/442-1196	32
Ultrox International, Inc., Santa Ana, CA (March 1989)	Ultraviolet Radiation, Hydrogen Peroxide, and Ozone	Lorentz Barrel and Drum Company in San Jose, CA	March 8, 1989	SITE Program Demonstration of the Ultrox International Ultraviolet Radiation/Oxidation Technology, EPA/540/5-89/012, September 1989	In preparation	Joseph Healy EPA Region IX 415/974-8011	98
Soliditech, Inc., Houston, TX (December 1988)	Solidification/ Stabilization	Imperial Oil Company/Champion Chemicals Superfund site in Morganville, Monmouth County, NJ	December 7, 1988	SITE Program Demonstration Test - Soliditech, Inc. Solidification/Stabilization Process, EPA/540/5-89/005, September 1989	In preparation	Trevor Anderson EPA Region II 212/264-5391	88
CF Systems Corporation, Waltham, MA (September 1988)	Solvent Extraction	New Bedford Harbor Superfund Site in Massachusetts	August 26 - 27, 1988	SITE Program Demonstration Test - CF Systems Corporation Solvent Extraction, EPA/540/5-90/002, May 1990	Applications Analysis Report: SITE Program, CF Systems Organics Extraction System, New Bedford, MA, EPA/540/AS-90/002, May 1990	David Lederer EPA Region I 617/573-9665	30

COMPLETED SITE DEMONSTRATIONS AS OF NOVEMBER 1990

DEVELOPER	TECHNOLOGY	SITE LOCATION	VISITOR'S DAY	TECHNOLOGY EVALUATION REPORT	APPLICATIONS ANALYSIS REPORT	REGIONAL CONTACT	PROFILE PAGE NO.
International Waste Technologies, Wichita, KS/GeoCon, Inc., Pittsburgh, PA (May 1988)	In-Situ Stabilization/ Solidification	General Electric Service Shop in Hialeah, FL	April 14, 1988	Technology Evaluation Report, SITE Demonstration Program, International Waste Technologies In Situ Stabilization/ Solidification, Hialeah, Florida, EPA/540/5-89/004a, August 1989	Applications Analysis Report: International Waste Tech/ Geo-Con, Inc. In-Situ Stabilization/ Solidification, EPA/540/A5-89/004, August 1989	James Orban Region IV 404/347-2643	62
Terra Vac, Inc., San Juan, Puerto Rico (December 1987 through April 1988)	In Situ Vacuum Extraction	Groveland Wells Superfund Site, Valley Manufactured Product	January 15, 1988	SITE Program Demonstration Test Terra Vac In Situ Vacuum Extraction System, Groveland, Massachusetts, EPA/540/5-89/003a, April 1989	Terra Vac In Situ Vacuum Extraction System, EPA/540/A5-89/003, July 1989	Robert Leger EPA Region I 617/573-5734	92
American Combustion Technologies, Inc., Norcross, GA (January 1988)	Pyretron Thermal Destruction	EPA's Combustion Research Facility in Jefferson, AK Soil from Stringfellow Acid Pit Superfund Site in California	Demonstration conducted from November 16, 1987 to January 29, 1988	SITE Program Demonstration Test: The American Combustion Pyretron Thermal Destruction System at the U.S. EPA's Combustion Research Facility, EPA/540/5-89/008, April 1989	American Combustion Pyretron Destruction System: Applications Analysis Report, EPA/540/A5-89/008, April 1989	Laurel Staley EPA ORD, Cincinnati 513/569-7863	20

COMPLETED SITE DEMONSTRATIONS AS OF NOVEMBER 1990

DEVELOPER	TECHNOLOGY	SITE LOCATION	VISITOR'S DAY	TECHNOLOGY EVALUATION REPORT	APPLICATIONS ANALYSIS REPORT	REGIONAL CONTACT	PROFILE PAGE NO.
Shirco Infrared Systems, Carollton, TX (November 1987)	Infrared Thermal Destruction	Rose Township Superfund Site, Oakland County, MI	November 4, 1987	SITE Program Demonstration Test, Shirco Pilot-Scale Infrared Incineration System at the Rose Township Demode Road Superfund Site, EPA/540/5-89/007a, Vol. 1, April 1989	Shirco Infrared Incineration System, EPA 540/A5-89/007, June 1989	Kevin Adler EPA Region V 312/886-7078	84
IM-Tech (formerly Hazcon, Inc.), Oakwood, TX (October 1987)	Solidification/ Stabilization	Douglassville Superfund Site, Berks County, near Reading, PA	October 14, 1987	SITE Program Demonstration Test, HAZCON Solidification, Douglassville, PA, EPA 540/5-89/001a, Vol. 1, May 1989	HAZCON Solidification Process, Douglassville, Pennsylvania, EPA/540/AS-89/001, May 1989	Victor Janosik EPA Region III 215/597-8996	56
Shirco Infrared Systems, Carollton, TX (September 1987)	Infrared Thermal Destruction	Peak Oil Superfund Site in Brandon, FL	Demonstration conducted July 31 - August 5, 1987	SITE Program Demonstration Test, Shirco Infrared Incineration System, Peak Oil, Brandon, Florida, September 1988, EPA 540/5-88/002a	Shirco Infrared Incineration System, EPA/540/AS-89/010, June 1989	Fred Stroud EPA Region IV 404/347-3931	84

The technical reports listed above may be obtained by calling the Center for Environmental Research Information (CERI) in Cincinnati, Ohio at 513-569-7562. If you would like to be placed on the SITE mailing list, write to:

ORD Publications
26 West Martin Luther King Drive (G72)
Cincinnati, Ohio 45268

SITE Demonstration Program Participants

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Allied Signal Corporation [formerly Detox, Inc.] Morristown, NY (003)	Submerged Aerobic Fixed-Film Reactor	David Allen 201-455-5595	Ronald Lewis 513-569-7856 FTS 684-7856	Ground Water, Wastewater	Certaom Metals Inhibit the Process	Readily Biodegradable Organic Compounds
American Combustion Technologies, Inc. Norcross, GA (001)	Pyretron Oxygen Burner	Gregory Gitman 404-662-8156	Laurel Staley 513-569-7863 FTS 684-7863	Soil, Sludge, Solid Waste	NA	Non-specific
AWD Technologies, Inc. San Francisco, CA (004)	Integrated Vapor Extraction and Steam Vacuum Stripping	David Bluestein 415-876-1504	Norma Lewis/ Gordon Evans 513-569-7665/ 513-569-7684	Ground Water, Soil	NA	Volatile Organic Compounds
Biotrol, Inc. Chaska, MN (003)	Biological Aqueous Treatment System	John Sheldon 612-448-2515	Mary Stinson 908-321-6683 FTS 340-6683	Liquid Waste, Ground Water	Nitrates	Chlorinated and Nonchlorinated Hydrocarbons, Pesticides
Biotrol, Inc. Chaska, MN (003)	Soil Washing System	John Sheldon 612-448-2515	Mary Stinson 908-321-6683 FTS 340-6683	Soil	Metals	High Molecular Weight Organics, PAHs, PCP, PCBs, and Pesticides
BioVersal USA, Inc. Mount Prospect, IL (005)	BioGenesis Process for Extraction of Hydrocarbons	Mohsen C. Amiran 708-228-7316	Diana Guzmán 513-569-7819 FTS 684-7819	Soil	NA	Volatile and Nonvolatile Hydrocarbons
CF Systems Corporation Waltham, MA (002)	Solvent Extraction	Chris Shallice 617-890-1200	Laurel Staley 513-569-7863 FTS 684-7863	Soil, Sludge, Wastewater	NA	PCBs, Volatile, and Semivolatile Organics, Petroleum Byproducts

NA = Non Applicable

SITE Demonstration Program Participants

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Chemfix Technologies, Inc. Metairie, LA (002)	Solidification/Stabilization	Philip Baldwin 504-831-3600	Edwin Barth 513-569-7669 FTS 684-7669	Soil, Sludge, Solids, Waste, Electroplating Wastes	Heavy Metals	High Molecular Weight Organics
Chemical Waste Management, Inc. Geneva, IL (003)	X*TRAX™ Low-Temperature Thermal Desorption	Carl Swanstrom 708-513-4578	Paul dePercin 513-569-7797 FTS 684-7797	Soil, Sludge, Other Solids	NA	Volatile and Semivolatile Organics, PCBs
Dehydro-Tech Corporation East Hanover, NJ (004)	Carver-Greenfield Process for Extraction of Oily Waste	Thomas Holcombe 201-887-2182	Laurel Staley 513-569-7863 FTS 684-7863	Soil, Sludge	NA	PCBs, Dioxin, Oil-Soluble Organics
E.I. Du Pont de Nemours and Co./Oberlin Filter Co. Newark, DE (003)	Membrane Microfiltration	Ernest Mayer 302-366-3652	John Martin 513-569-7758 FTS 684-7758	Ground Water, Leachate, Wastewater, Electroplating Rinsewaters	Heavy Metals, Cyanide, Uranium	Non-specific
Ecova Corporation Redmond, WA (003)	In-Situ Biological Treatment	Michael Nelson 206-883-1900	Naomi Barkley 513-569-7854 FTS 684-7854	Water, Soil, Sludge, Sediment	NA	Chlorinated and Nonchlorinated Organic
EPOC Water, Inc. Fresno, CA (004)	Precipitation and Microfiltration, and Sludge Dewatering	Ray Groves 209-291-8144	S. Jackson Hubbard 513-569-7507 FTS 684-7507	Sludge, Wastewater, Leachable Soil	Heavy Metals	Pesticides, Oil, and Grease
Excalibur Enterprises, Inc. New York, NY (004)	Soil Washing/Catalytic Ozone Oxidation	Lucas Boeve 212-484-2699	Norma Lewis 513-569-7665 FTS 684-7665	Soil, Sludge, Leachate, Ground Water	Cyanide	Semivolatiles, Pesticides, PCBs, PCP, Dioxin

NA = Non Applicable

SITE Demonstration Program Participants

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Excavation Techniques -- Not Specific to a Developer	Excavation Techniques and Foam Supression Methods	Dick Gerstle 513-782-4700	S. Jackson Hubbard 513-569-7507 FTS 684-7507	Soil	Volatile Inorganics	Volatile Organics
Exxon Chemicals, Inc./ Rio Linda Chemical Co. Long Beach, CA (004) [2 Demonstrations]	Chemical Oxidation/Cyanide Destruction	Tony Kurpakus 213-597-1937	Teri Shearer 513-569-7949 FTS 684-7949	Ground Water, Wastewater, Leachate	Cyanide	Non-specific
Freeze Technologies Corp. Raleigh, NC (003)	Freezing Separation	James A. Heist 919-850-0600	S. Jackson Hubbard 513-569-7507 FTS 684-7507	Liquids	Non-specific	Non-specific
GeoSafe Corporation Kirkland, WA (002)	In-Situ Vitrification	James Hansen 206-822-4000	Teri Shearer 513-569-7949 FTS 684-7949	Soil, Sludge	Non-specific	Non-specific
Horsehead Resources Development Co., Inc. Monaca, PA (004)	Flame Reactor	John Pusater 412-773-2279	Donald Oberacker 513-569-7510 FTS 684-7510	Soil, Sludge, Industrial Solid Residues	Metals	NA
IM-Tech [formerly Hazcon, Inc.] Oakwood, TX (001)	Solidification/Stabilization	Ray Funderburk 800-227-6543	Paul dePercin 513-569-7797 FTS 684-7797	Soil, Sludge	Heavy Metals	Non-specific
In-Situ Fixation Co. Chandler, AZ (005)	In-situ Bioremediation	Richard P. Murray 602-821-0409	Edward J. Opatken 513-569-7855 FTS 684-7855	Soil, Sludge	NA	Biodegradable Organics

NA = Non Applicable

SITE Demonstration Program Participants

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
International Environmental Technology/YWC Midwest North Canton, OH (005)	Geolock/Bio-drain Treatment	Lynn D. Sherman 216-499-8181	Randy Parker 513-569-7271 FTS 684-7271	Soil	NA	Most
International Waste Technologies/Geo-Con, Inc. Wichita, KS (001)	In-Situ Solidification/ Stabilization	Jeff Newton 316-269-2660 Brian Jasperse 412-856-7700	Mary Stinson 908-321-6683 FTS 340-6683	Soil, Sediment	Non-specific	PCBs, PCP, Other Non-specific Organic Compounds
Ogden Environmental Services San Diego, CA (001)	Circulating Fluidized Bed Combustor	Harold Diot 619-455-2613	Joseph McSorley 919-541-2920 FTS 629-2920	Soil, Sludge, Slurry	NA	Halogenated and Nonhalogenated Organic Compounds
QUAD Environmental Technologies Corp. Northbrook, IL (004)	Chemtact Gaseous Waste Treatment	Harold Rafson 312-564-5070	Ronald Lewis 513-569-7856 FTS 684-7856	Gaseous Waste Streams	Non-specific	Volatile Organics
Recycling Sciences International, Inc. Chicago IL (004)	Desorption and Vapor Extraction System	William C. Meenan 312-559-0122	Laurel Staley 513-569-7863 FTS 684-7863	Soil, Sludge, Sediment	Volatile Inorganics	Volatile and Semivolatile Organics including PCBs, PAHs, PCP, some Pesticides
Remediation Technologies, Inc. [formerly MoTec] Austin, TX (002)	Liquid/Solid Contact Digestion	Randy Kabrick 512-477-8661	Ronald Lewis 513-569-7856 FTS 684-7856	Soil, Sludge, Liquid Waste	NA	Halogenated and Nonhalogenated Organic Compounds, Pesticides
Resources Conservation Co. Bellevue, WA (001)	Solvent Extraction (BEST)	Paul McGough 206-828-2400	Edward Bates 513-569-7774 FTS 684-7774	Soil, Sludge	NA	Non-specific Organics, Oil

NA = Non Applicable

SITE Demonstration Program Participants

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Retech, Inc. Ukiah, CA (002)	Plasma Reactor	R.C. Eschenbach 707-462-6522	Laurel Staley 513-569-7863 FTS 684-7863	Liquids, Soil, Sludge	Metals	Non-specific
Risk Reduction Engineering Laboratory Cincinnati, OH	Debris Washing System	Michael Taylor 513-782-4801	Naomi Barkley 513-569-7854 FTS: 684-7854	Soil Debris	Non-specific	Non-specific Organics, PCBs, Pesticides
Sanivan Group Anjou, Quebec (005)	Soil Treatment with Extrasol	Peter Z. Colak 514-355-3351	Mark Meckes 513-569-7348 FTS 684-7348	Soil	NA	PCBs, PCP, PAH, MAH, Pesticides, Oils, Hydrocarbons
S.M.W. Seiko, Inc. Redwood City, CA (004)	In-Situ Solidification/ Stabilization	David Yang 415-591-9646	S. Jackson Hubbard 513-569-7507 FTS 684-7507	Soil	Metals	Semivolatile Organic Compounds
Separation and Recovery Systems, Inc. Irvine, CA (002)	Solidification/Stabilization	Joseph DeFranco 714-261-8860	Walter Grube 513-569-7798 FTS 684-7798	Sludge	Low Level Metals	Acidic Sludges with at Least 5% Hydrocarbons
Shirco Infrared Systems, Inc. Redmond, WA (001) [2 Demonstrations]	Infrared Thermal Destruction	Several Vendors (see Technology Profile)	Howard Wall 513-569-7691 FTS 684-7691	Soil, Sediment	NA	Non-specific
Silicate Technology Corp. Scottsdale, AZ (003)	Solidification/Stabilization with Silicate Compounds	Steve Pegler 602-941-1400	Edward R. Bates 513-569-7774 FTS 684-7774	Soil, Sludge, Ground Water	Metals, Cyanide, Ammonia	High Molecular Weight Organics
Soliditech, Inc. Houston, TX (002)	Solidification/Stabilization	Bill Stallworth 713-497-8558	Walter Grube 513-569-7798 FTS 684-7798	Soil, Sludge	Metals	Non-specific

NA = Non Applicable

SITE Demonstration Program Participants

Developer	Technology	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
Techtran, Inc. Houston, TX (005)	Chemical Binding/ Precipitation and Physical Separation	Tod S. Johnson 713-896-8205	Annette Gatchett 513-569-7697 FTS 684-7697	Aqueous Solutions	Heavy Metals	Non-specific
Thermal Waste Management New Orleans, LA (005)	Production of Fossil Fuel from Petroleum-Based Sludges	George Lane 504-525-9722	Paul dePercin 513-569-7797 FTS 684-7997	Sludge	NA	Petroleum Sludge
Terra Vac, Inc. San Juan, PR (001)	In-Situ Vacuum Extraction	James Malot 809-723-9171	Mary Stinson 908-321-6683 FTS 340-6683	Soil	NA	Volatile and Semivolatile Organic Compounds
Toxic Treatments (USA) Inc. San Francisco, CA (003)	In-Situ Steam/Air Stripping	Philip La Mori 415-391-2113	Paul dePercin 513-569-7797 FTS 684-7797	Soil	NA	Volatile Organic Compounds and Hydrocarbons
Ultrox International, Inc. Santa Ana, CA (003)	Ultraviolet Radiation and Ozone Treatment	David Fletcher 714-545-5557	Norma Lewis 513-569-7665 FTS 684-7665	Ground Water, Leachate, Wastewater	NA	Halogenated Hydrocarbons, Volatile Organic Compounds, Pesticides, PCBs
Wastech, Inc. Oak Ridge, TN (004)	Solidification/Stabilization	E. Benjamin Peacock 615-483-6515	Edward Bates 513-569-7774 FTS 684-7774	Soil, Sludge, Liquid Waste	Non-specific, Radioactive	Non-specific
Zimpro/Passavant, Inc. Rothschild, WI (002)	PACT®/Wet Air Oxidation (Powdered activated carbon and biological treatment)	William Copa 715-359-7211	John Martin 513-569-7758 FTS 684-7758	Ground Water, Industrial Wastewater, Leachate	NA	Biodegradable Volatile and Semivolatile Organic Compounds

NA = Non Applicable

EPA

DOCUMENTS AVAILABLE FROM THE U.S. EPA RISK REDUCTION ENGINEERING LABORATORY SUPERFUND TECHNOLOGY DEMONSTRATION DIVISION MARCH 1991

The following technical publications and SITE demonstration project results are available from EPA. Indicate your choice by checking the appropriate box(es) on the order form below.*

General Publications

- ☐ Technology Profiles (EPA/540/5-90/006)
- ☐ SITE Program - FY89, Report to Congress (EPA/540/5-90/001)

Demonstration Project Results

American Combustion - Oxygen Enhanced Incineration

- ☐ Technology Evaluation (EPA/540/5-89/008)
- ☐ Applications Analysis (EPA/540/A5-89/008)

CF Systems Corp. - Solvent Extraction

- ☐ Technology Evaluation (EPA/540/5-90/002)
- ☐ Applications Analysis (EPA/540/A5-90/002)

Chemfix Technologies, Inc. - Chemical Fixation/Stabilization

- ☐ Technology Evaluation (EPA/540/5-89/011)
- ☐ Applications Analysis (EPA/540/A5-89/011)

Hazcon - Solidification

- ☐ Technology Evaluation (EPA/540/5-89/001a)
- ☐ Applications Analysis (EPA/540/A5-89/001)

IWT In-Situ Stabilization

- ☐ Technology Evaluation (EPA/540/5-89/004a)
- ☐ Applications Analysis (EPA/540/A5-89/004)

Shirco-Infrared Incineration

- ☐ Technology Evaluation - Peake Oil (EPA/540/5-88/002a)
- ☐ Technology Evaluation - Rose Township (EPA/540/5-89/007a)
- ☐ Applications Analysis (EPA/540/A5-89/007)

Soliditech, Inc. - Solidification

- ☐ Technology Evaluation (EPA/540/5-89/005a)
- ☐ Applications Analysis (EPA/540/A5-90/005)

Terra Vac - Vacuum Extraction

- ☐ Technology Evaluation (EPA/540/5-89/003a)
- ☐ Applications Analysis (EPA/540/A5-89/003)

Ultrox International - Ultraviolet Ozone Treatment for Liquids

- ☐ Technology Evaluation (EPA/540/5-89/012)
- ☐ Applications Analysis (EPA/540/A5-89/012)

Emerging Program Reports

Bio-Recovery Systems Removal and Recovery of Metal Ions from Groundwater

- ☐ EPA/540/5-90/005a

Development of Electro-Acoustic Soil Decontamination (ESD) Process for In Situ Applications

- ☐ EPA/540/5-90/004

Removal and Recovery of Metal Ions from Groundwater

- ☐ EPA/540/5-90/005

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United States Environmental Protection Agency | Office of Solid Waste and Emergency Response | 9380.0-17FS August 1991

Furthering the Use of Innovative Treatment Technologies in OSWER Programs

Introduction

The Office of Solid Waste and Emergency Response (OSWER) is seeking to further the use of innovative treatment technologies to permanently clean-up contaminated sites in the Superfund, RCRA, and Underground Storage Tank (UST) programs. According to a directive from OSWER's Assistant Administrator Don Clay, "...we must invest the necessary resources and take the risks now to develop the technologies necessary to fulfill the long-term needs of our hazardous waste clean-up programs." The directive, which was signed on June 10, 1991, includes a forwarding memorandum to EPA regions that calls for technological leadership and a sense of responsible urgency to prevent expenditures in pursuing less effective or more costly remedies. This fact sheet is based on OSWER Directive 9380.0-17.

Reasonable risk-taking is encouraged in selecting innovative treatment technologies that are capable of treating contaminated soils, sludges, and ground water more effectively, less expensively, and in a manner more acceptable to the public than existing conventional methods.

"Innovative treatment technologies" are newly-developed technologies that lack sufficient full-scale application data to ensure their routine consideration for site remediation. They may be new technologies, or may already be in use for various industrial applications other than hazardous waste remediation. As such, innovative technologies are not part of standard engineering practice or the competitive market process where available alternatives are routinely presented to the government and private sector. In functional terms, OSWER labels as "innovative" those treatment technologies other than incineration and solidification/stabilization for source control, and other than pumping with conventional treatment for ground water.

Inherent risks associated with early technology use serve as very serious impediments. The directive calls on potentially responsible parties, facility owners/operators, and consulting engineers to constructively work with uncertainty to further the application of technologies that are truly innovative. The directive also calls on EPA regional and headquarters managers to support Remedial Project Managers and On-Scene Coordinators in their efforts to use new technologies.

Innovative treatment technologies should be routinely considered as an option in engineering studies where treatment is appropriate. They should not be eliminated from consideration solely because of uncertainties in their performance and cost. These technologies may be found to be cost-effective, despite the fact that their costs are greater than conventional options, after consideration of potential benefits including increased protection, superior performance, and greater community acceptance. In addition, future sites will benefit by information gained from the field experience.

The directive sets forth several initiatives and new procedures that will provide incentives for broader use of innovative technology. Some of these initiatives are directed toward potentially responsible parties and owner/operators, since these groups will be assuming a larger share of the remedial projects in the future. Other new initiatives are intended to remove impediments to the first-time use of new equipment. The directive also encourages wider application of available resources and tools and highlights some important on-going program efforts.

New Initiatives

1. Superfund Innovative Technology Start-Up Initiative

OERR will be revising its procedures for setting Remedial Action funding priorities to give more consideration to innovative technologies. Expedited funding of Fund-lead remedial design and construction projects that involve innovative treatment technologies will move the agency toward the Superfund program's goals for technology development and will provide data to support future Records of Decision (RODs).

This initiative also provides contract flexibility in the start-up phase of selected remedial and removal actions to assist vendors in establishing operations that satisfy performance standards. In an effort to remove some of the impediments to the use of new full-scale equipment, this initiative will provide financial support for initial start-up and shake-down prior to beginning actual remediation. Funds are not targeted at making the technology "work at any cost", but in establishing performance adequacy of the technology prior to the onset of the contracted cleanup.

Contracting strategies are being considered to compensate vendors regardless of whether or not they are able to meet performance requirements.

2. Dual Track RI/FS Initiative (Superfund)

EPA regions may fund additional treatability studies and engineering analyses for promising treatment technologies that would otherwise be considered unproven or too early in the development process. For PRP-lead sites early in the planning process, this initiative encourages the use of treatability studies to ensure that alternative remedies are thoroughly evaluated and considered in the ROD. Even if, in a particular case, there may be some doubt as to EPA's ability to recover the costs for these additional studies, they should nonetheless be pursued because of their value to the overall program.

3. Tandem ROD Evaluation Initiative (Superfund)

Primarily applicable to PRP-lead sites (though also to some Fund-lead sites), this program will enable regional staff to rapidly evaluate the efficacy of a PRP-proposed innovative remedy that is offered in tandem with the primary one approved in the ROD. Both remedies would be part of the proposed plan. The alternate solution would be approved in the ROD on a contingent basis but would undergo further development and pilot testing during the design period of the primary technology. Tandem RODs move the process of cleanup toward closure while leaving room for PRPs with an interest in innovative technologies to pursue additional pilot tests to demonstrate an alternate approach that is both innovative and potentially cost-effective. The OSWER/ORD Technical Support Centers and the SITE Demonstration Program will provide RPMs with technical support for evaluation of PRP work. When considering a tandem ROD, the region should consult with ORD concerning the scope of effort required for the evaluation.

If, after testing and evaluation, the innovative technology is chosen for implementation but the process has caused significant delays to the schedule, the region may consider the engineering problems of making the full-scale unit operational when assessing stipulated penalties. That is, in limited cases, stipulated penalties should not be imposed if the delays are the unavoidable result of the use of an innovative process.

4. Removal Program Initiative (Superfund)

It is OSWER policy to further the use of innovative technologies through the removal program. The relatively small waste volumes and streamlined contracting procedures of the removal program provide an opportunity to complete clean-up projects and provide documentation on "lessons learned".

The potential of the removal program for these applications has not been realized because time constraints often favor excavation and off-site disposal or treatment and also because of the absence of clear legislated goals regarding the use of new technology. This directive is meant to clarify EPA's position on this issue and to encourage the use of innovative technologies for all actions, including time-critical actions, where feasible. These projects are expected to fulfill an important role in adding to our knowledge on promising new technologies.

5. RCRA Corrective Action and Closure Innovative Technology Initiative

This initiative encourages the regions to conduct treatability or technology demonstration studies at corrective action and closure sites to gain additional information on the use of innovative treatment for contaminated soil and debris.

EPA is developing best demonstrated available technology (BDAT) treatment standards for contaminated soil and debris at CERCLA and RCRA corrective action and closure sites. These sites present unique treatment problems that were not considered when developing the current BDAT standards which were based on data from the treatment of industrial process wastes. There is general agreement that wide scale use of incineration is not appropriate for soil and debris and there is a need to explore alternative approaches.

The current schedule is to promulgate a rule for the treatment of debris in May 1992 and for soil in April 1993. Prior to publication of these final rules, a site-specific treatability variance process (40 CFR 268.44 (h)) is available for contaminated soil and debris to establish an alternative standard for specified waste at individual sites. The variance process, along with applicable guidance treatment levels is described in Superfund LDR Guide #6A (OSWER Directive 9347.3-06FS, July 1989), and is intended to be used as an interim approach until final standards are established. The regions should work with owner/operators to select pilot-scale projects that can provide data on the capability of technologies and the treatability of different wastes.

Authority for issuing site-specific variances for contaminated soil and debris has been delegated to the regions. The facility and EPA, in collaboration with the state, can implement variances for on-site demonstrations through two mechanisms: temporary authorization under the Permit Modification Rule, or 3008(h) orders for interim-status facilities.

6. Demonstration Projects at Federal Facilities (Superfund, RCRA, and UST)

EPA is exploring the use of Federal Facilities for both site-specific technology demonstrations and as test locations for evaluation of more widely applicable technologies. Regions are encouraged to suggest innovative approaches and to be receptive to proposals for innovation from Federal Facility managers, *e.g.*, by building timing

and performance flexibility into compliance agreements in acknowledgment of the uncertainties associated with innovation. Federal Facilities often have characteristics that make them desirable for applying innovative approaches: large area, isolated locations, controlled access, numerous contamination problems, and increasingly active environmental restoration programs.

The Office of Federal Facilities Enforcement (OFFE) and the Technology Innovation Office (TIO) will work with the regions to identify locations for test and evaluation activities and to develop policies and guidance to ensure that support for innovation is congruent with other program and environmental objectives.

Federal Technology Transfer Act

During the clean-up planning and implementation process, PRPs or owner/operators should be reminded of the opportunity to engage EPA in evaluation studies or other arrangements (at their expense) to determine whether an innovative technology would be operative in the situation they are facing or other similar situations. Under the Federal Technology Transfer Act (FTTA) of 1986, cooperative agreements related to research, development, and technology transfer will allow the PRP to reimburse EPA for facilities, support services, and staff time spent in joint evaluation of early technology treatability or pilot studies.

Since this program is conducted in the research and development arena, it offers an opportunity for non-adversarial interaction outside the regulatory context. This opportunity should be especially advantageous to (1) PRPs and owner/operators capable of early planning for technology options at a few sites and desirous of early EPA input, as well as (2) PRPs and owner/operators that will be faced with a number of similar waste sites in the future—under Superfund, RCRA Corrective Action, and the UST program—who want to develop more uniform, cost-effective technology proposals for such sites.

Implementation

The first six initiatives involve field testing new technologies that may benefit from technical assistance from ORD. ORD represents an objective third party that can easily be accessed through the existing OSWER/ORD support structure. This structure consists of five laboratories that constitute the Technical Support Centers (both for Superfund and newly established for RCRA), the Superfund Technical Assistance Response Team (START) Program, the Bioremediation Field Initiative, and the Superfund Innovative Technology Evaluation (SITE) Program. OSWER has asked ORD to give priority to requests for technical assistance under this directive.

Broader Application of Existing Policies, Available Resources, and Tools

Furthering Innovative Remediation at Leaking UST Sites

State and local UST programs have identified 100,000 confirmed leaks, and this number may triple in the next several years. Most site remediation involves pumping and treating ground water and excavation and off-site treatment of contaminated soils. Regional offices should increase their efforts to make state and local managers and staff, as well as clean-up consultants and contractors, more familiar with non-traditional but proven technologies. Headquarters will continue fostering the development of new tools and techniques and should increase its support of regional efforts to achieve broader use of improved technologies.

Further Enabling State Innovative Technology Leadership

The CERCLA core funding program provides an opportunity to assist states in establishing innovative technology advocates. Cooperative agreements with state response programs may be a vehicle to support and promote the use of innovative technologies in state CERCLA programs, with spinoff benefits for their RCRA and UST programs as well.

In addition, regions should be open to assisting states interested in furthering technology development and encourage state applications for authority for RCRA R&D permitting, permit modification, treatability exclusion, and Subpart X permitting. States may also want to work directly with Federal Facilities in developing pilot sites for innovative technologies. For the reasons discussed in the section on Federal Facilities above, these sites are often good candidates for such development projects.

Model RI/FS Work Plan and PRP Notice Letter Demand for Innovative Options

Some regions have issued special notices containing a Statement of Work and administrative order language requiring the responsible party to evaluate the use of innovative technologies at a particular site. This procedure should receive broader use at Superfund sites where alternatives for remediation are being considered for analysis in the RI/FS and where prerequisite treatability studies are required. This requirement in the special or general notice letters will help facilitate the development and use of innovative treatment technologies by the private sector. Specific language for this approach can be developed from OWPE's guidance document entitled "Model Statement of Work for RI/FSs Conducted by PRPs" (OSWER Directive 9835.8).

Advocacy and Funding of Treatability Studies

Superfund program policy requires that treatability studies be conducted to generate data to support the implementation of treatment technologies. Funds are budgeted annually in the SCAP based on expected need. Data and reports should be sent to Glen Shaul at RREL for inclusion in the ATTIC database. The correct protocol and format for these reports is in EPA's "Guide for Conducting Treatability Studies Under CERCLA" (EPA/540/2-89/058). Oversight funding for evaluating a PRP-lead treatability study should also be requested through the SCAP budget process. Oversight of PRP-lead treatability studies may be funded through the enforcement budget. If a PRP recommends use of an innovative treatment at a site, but current treatability study data on the technology are insufficient, EPA policy allows the Agency to conduct and fund technology-specific treatability studies. Cost of these studies are recoverable under Section 107 of CERCLA.

Tracking and Expediting SITE Demonstrations

OSWER is encouraging greater participation in the SITE program in response to a recent Inspector General audit of the program that focused on delays in matching Superfund sites with technologies. ORD management has also agreed that SITE demonstration projects must be more responsive to regional needs for treatability data.

The SITE program will make the design of technology evaluation sufficiently flexible to meet the regional offices' needs for treatability studies before remedy selection is made. Based on an ORD internal management review of the SITE program, changes are underway to make the program a more integral component of regional Superfund site activities.

Existing Program Efforts

OSWER has several other ongoing efforts directed toward furthering the application of innovative alternatives. These represent important resources that should continue to be used by the UST, RCRA, and Superfund Programs.

Technical Support and Information Management

EPA maintains several computer database that may be accessed for information on treatment technologies. These databases include the Alternative Treatment Technology Information Center (ATTIC), the Cleanup Information (CLU-IN) Bulletin Board, the ROD Database, the Hazardous Waste Collection Database, and the Computerized On-Line Information System (COLIS). These systems include information on the application of innovative technologies and may be used to aid networking among OSCs and RPMs.

Technical assistance is available to Superfund and RCRA staff through ORD's Technical Support Centers and the Environmental Response Branch of OERR. Part of this effort involves networking among project managers through the Engineering and Ground Water Forums. In addition, as part of an initiative to provide direct technical support to OSCs and RPMs, the Superfund Technical Assistance Response Team (START) has been established to help evaluate the potential use of technologies.

Bioremediation Field Initiative

Begun in the fourth quarter of FY 1990, this program is intended to provide more real-time information on the field application of biotechnology for treating hazardous waste. The major focus of this initiative is to furnish direct support in evaluating full-scale cleanup operations and technical assistance for conducting treatability and pilot-scale studies.

Eliminating Contract Impediments

Under the Federal Acquisition Regulations, firms are restricted from performing both the design and construction of a project. EPA has determined that this applies only to the prime contractor responsible for the overall design, and not to the subcontractors performing treatability studies.

Innovative technology is considered a special exception from general conflict of interest guidelines. EPA will permit contractors and/or subcontractors who perform evaluation of innovative technologies for the Agency to later work for the PRPs in as many instances as possible.

Additional Information

Copies of the policy (OSWER Directive 9380.0-17) and additional copies of this fact sheet are available from:

National Technical Information Service (NTIS)
Springfield, VA 22161
Phone (703) 487-4650

Agency and State employees may obtain copies of the directive or this fact sheet from the Superfund Document Center, U. S. Environmental Protection Agency, Room 2514, 401 M Street S.W., Washington, DC 20460. The telephone number is FTS or 202/382-5628.

MARKET ASSESSMENT FOR INNOVATIVE TREATMENT TECHNOLOGIES

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

September 1991

Purpose To provide information to assist technology developers in assessing cleanup markets for Superfund, hazardous waste, and underground storage tanks.

Background Vendors and investors need data on the market for innovative technologies in order to make financing, development, and marketing decisions. Useful information includes site and waste characteristics (including chemical contaminants and material volumes), sites under consideration for Superfund Records of Decision (RODs), and upcoming construction opportunities. These data are often buried within the various offices of EPA, the States, and other Federal agencies.

Approach EPA will collect readily-available information on the numbers and types of contaminated sites. Data will be presented on State nonNPL sites, Federal facilities, CERCLIS sites, NPL sites, corrective action sites, and underground storage tanks.

Because more data are available for National Priorities List (NPL) sites, EPA will conduct a more detailed analysis on the types and volumes of contaminated material on NPL sites. Sites will be categorized by the type and source of the waste. For each category, estimates will be derived for total volumes of contaminated soil, as well as the volumes that are scheduled for remediation in upcoming fiscal years.

The study will also document the innovative technologies that have already been selected in RODs, the types and quantities of waste to be remediated, and known remediation schedules.

Plans are to publish a market monograph at regular intervals. Each monograph will update and expand on the previous documents.

Project Status The first monograph will be completed in the fall of 1991. EPA plans to conduct a meeting of outside advisors to obtain feedback on the utility of the initial monograph, and to develop new ideas for data and analyses to be included in future reports.

Contact To be placed on the mailing list to receive the market monographs, call Melinda DeLoatch at 703/308-8802. For further information on this project, contact Linda Fiedler at 703/308-8799.

11.8 TREATABILITY STUDIES

Current Status

Treatability studies are often required to assess the potential for application of a treatment technology at a specific site. Guidance documents currently exist, and technology-specific protocols are being prepared. A summary of these is provided below.

Available Guidance

Treatability Studies under CERCLA: An Overview, 12/89, OSWER Directive 9380.3-02FS (Fact Sheet).

The Remedial Investigation Site Characterization and Treatability Studies, OSWER Directive 9355.3-01FS1 (Fact Sheet).

Guide for Conducting Treatability Studies under CERCLA, Interim Final (Generic Protocol), EPA/540/2-89/058.

Inventory of Treatability Study Vendors, Draft Interim Final, EPA/540/2-90/003a.

Guide for Conducting Treatability Studies under CERCLA: Aerobic Biodegradation Remedy Screening, EPA 540/2-91/013

Protocols in Development

The following treatability study guides/protocols will be prepared with assistance from EPA's Office of Research and Development, Risk Reduction Engineering Laboratory:

- Soil washing
- Solidification/stabilization of inorganics
- Soil vapor extraction
- Chemical dehalogenation
- Low temperature desorption
- Solvent extraction

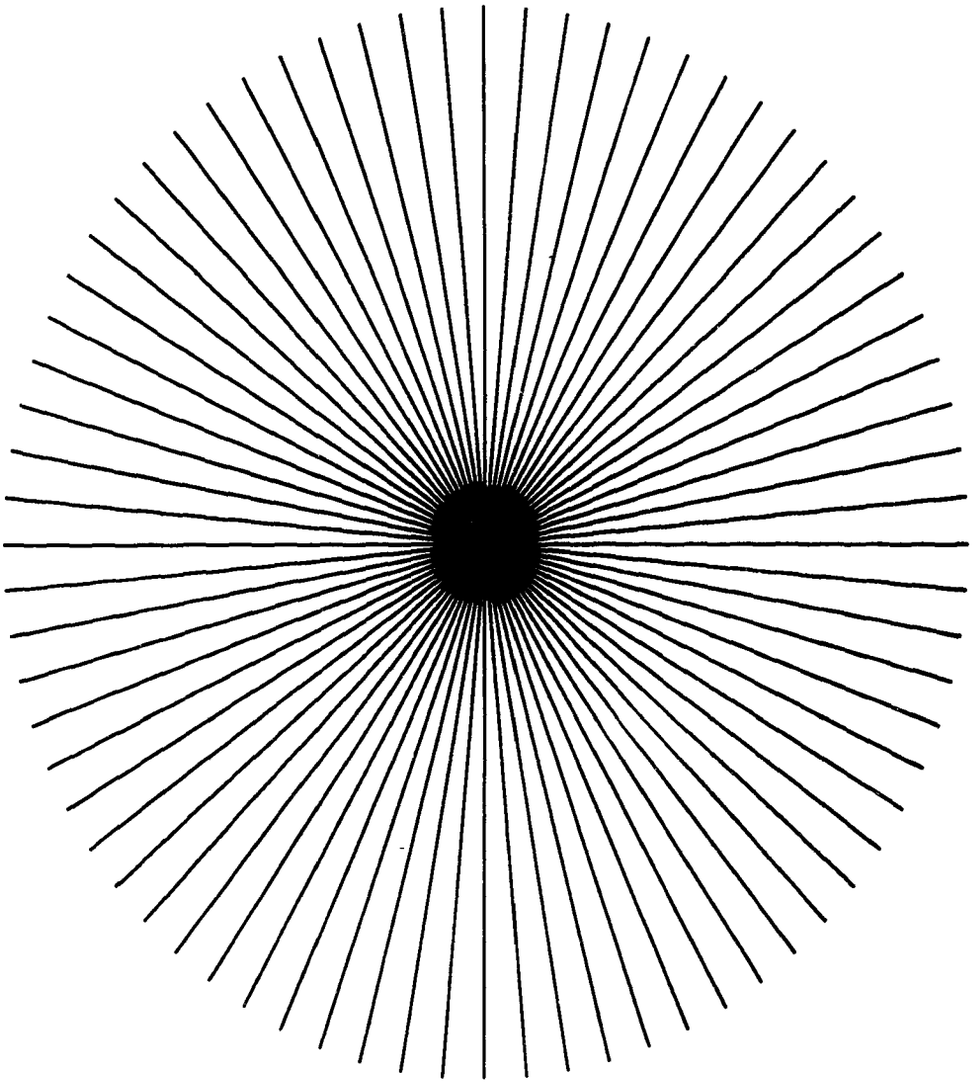
United States Environmental Protection Agency
Office of Solid Waste and Emergency Response Washington DC 20460
EPA/540/8-90/011
November 1990

Superfund

EPA

Technical Support Services for Superfund Site Remediation

Second Edition



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Use this chart to identify the programs that offer expertise in your area of concern. If you're not sure where to start, try one of the Regional Contacts listed in Appendix A, beginning on page 23 or call Rich Steimle in OSWER's Technology Innovation Office at FTS 382-7914—he'll get you connected with the right source.

Technical Support Services for Superfund Site Remediation

SECOND EDITION

Printed on Recycled Pape

Questions or comments on this document should be directed to:

Richard Steimle
U.S. Environmental Protection Agency (OS-110)
401 M Street, S.W.
Washington, DC 20460

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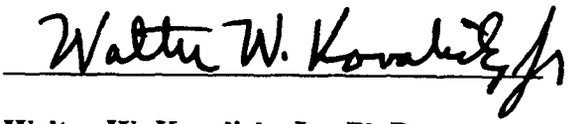
Preface

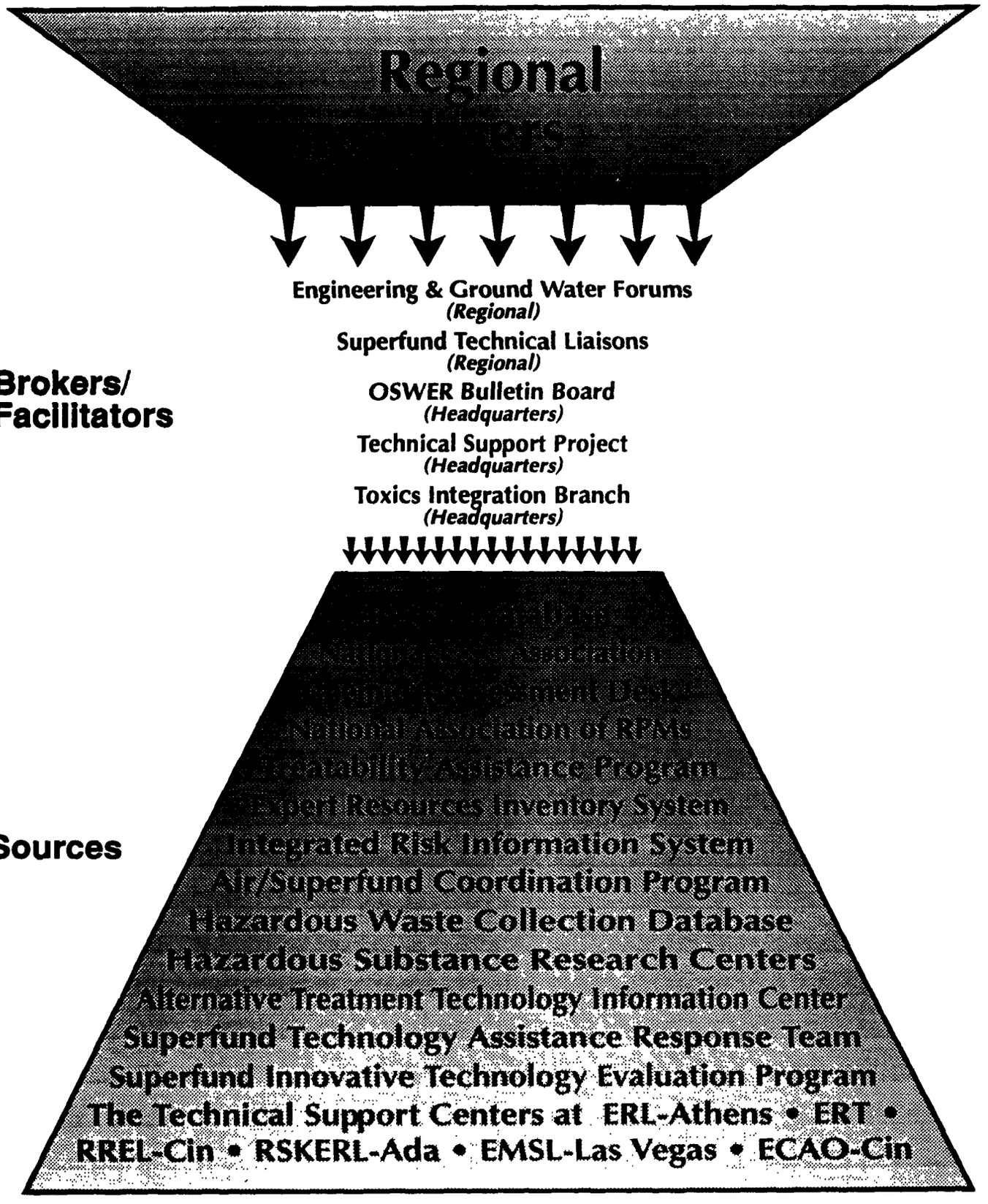
The Office of Solid Waste and Emergency Response and the Office of Research and Development provide numerous opportunities for technical assistance—some multi-faceted and others directed to specific topics. This Directory of Technical Support Services was first prepared in response to the Administrator's 90-Day Review of Superfund and the need to make such technical assistance more widely available. This edition has been updated with an organizational overview of the many sources and facilitators for technical assistance in addition to some additional sources and a restructured list of headquarters contacts.

The goal of this Directory is to enable EPA field staff to quickly identify the existing technical support services that will be most useful for their specific problem. Rather than an exhaustive inventory of all sources of technical information, this Directory highlights the significant OSWER and ORD technical assistance programs—those that have procedures in place to process requests for assistance (*e.g.*, answering a technical question, providing staff to work on the problem, or referring callers to the appropriate source). The Directory will allow users to access the most information with the least effort.



Walter W. Kovalick, Jr., Ph.D.
Director, Technology Innovation Office

An Organizational Overview of Superfund Technical Support



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Technical Support Sources and Brokers

Technical Support Project (TSP)*

Monitoring and Site Characterization Technical Support Center
Environmental Monitoring Systems Laboratory, Las Vegas (EMSL-LV)

Contact: Ken Brown
FTS 545-2270 or (702) 798-2270

EMSL, Las Vegas, Nevada, provides scientific and technical assistance in contaminant detection, hydrologic monitoring, site characterization, sample analysis, data interpretation, and geophysics. Services include:

- Saturated and unsaturated zone monitoring
- Remote sensing, mapping, and geostatistics
- Analytical methods and quality assurance
- Bore-hole and surface geophysics
- X-ray fluorescence field survey methods
- Mixed waste and radiological analysis

Ground-Water Fate and Transport Technical Support Center
Robert S. Kerr Environmental Research Laboratory (RSKERL)

Contact: Dick Scalf
FTS 743-2308 or (405) 332-8800

RSKERL, in Ada, Oklahoma, is EPA's center for fate and transport research, focusing its efforts on transport and fate of contaminants in the vadose and saturated zones of the subsurface,

* *The TSP is made up of six Technical Support Centers and two Technical Support Forums. It is a joint service of the Office of Solid Waste and Emergency Response, the Office Research and Development, and the Regions. The TSP offers direct site-specific technical assistance to OSCs and RPMs and develops technology workshops, issue papers, and other information for Regional staff. The TSP:*

- *Reviews contractor work plans, evaluates remedial alternatives, reviews RI/FS, assists in selection and design of final remedy*
- *Offers modeling assistance and data analysis and interpretation*
- *Assists in developing and evaluating sampling plans*
- *Conducts field studies (soil gas, hydrogeology, site characterization)*
- *Develops technical workshops and training, issue papers on ground-water and engineering topics, generic protocols*
- *Assists in performance of treatability studies*

methodologies relevant to protection and restoration of ground-water quality, and evaluation of subsurface processes for the treatment of hazardous waste. The Center provides technical assistance such as evaluating remedial alternatives; reviewing RI/FS and RD/RA workplans; and providing technical information and advice in:

- Pump and treat technology for aquifer remediation
- *In situ* biorestoration of soils and ground water
- Subsurface geochemistry
- Contaminant transport modeling
- Subsurface contaminant transformation

Subsurface Remediation Information Clearinghouse
Contact John Matthews at RSKERL at FTS 743-2233 or (405) 332-8800.

The Subsurface Remediation Information Clearinghouse was established at RSKERL to provide for transfer of up-to-date subsurface fate, transport, and remediation research and demonstration information. The Clearinghouse's technical information specialists locate, assess, and document pertinent information sources, including planned, active, or completed subsurface remediations. This information is used in the development and maintenance of four specific databases:

- Soil transport and fate database
- Subsurface remediation literature database
- Biotechnology/bioremediation practitioners database
- Subsurface remediation database

International Ground-Water Modeling Center (IGWMC)
Contact Cathy Mulberry at (317) 283-9458

RSKERL also supports the operation of the International Ground-Water Modeling Center (IGWMC) at the Holcomb Research Institute in Indianapolis, Indiana. IGWMC collects and disseminates information about ground-water modeling software. The Center compiles databases of descriptions of ground-water models and offers courses and seminars on the theory and application of ground-water models.

Exposure and Ecorisk Assessment Technical Support Center
Environmental Research Laboratory, Athens (ERL-Athens)

Contact: Bob Ambrose
FTS 250-3130 or (404) 546-3130

ERL, Athens, Georgia, emphasizes multimedia exposure and risk assessment modeling of remedial action alternatives. An electronic bulletin board has been established to disseminate models and databases and to exchange modeling information. The technical support services include:

- Models, databases, and analytical techniques
- Multimedia modeling of organic chemical and heavy metal pollutant fate
- Soil/water and surface water/sediment systems
- Ecological impact and ecorisk assessments

Environmental Response Team Technical Support Center
Environmental Response Team (ERT)

Contact: Joseph Lafornara
FTS 340-6740 or (201) 321-6740

ERT, in Edison, New Jersey, provides support in responding to releases of hazardous waste, chemicals, and oil. ERT also provides support in risk assessment, multi-media sampling and analysis, health and safety, cleanup techniques, and training for response personnel. Services include:

- Response techniques for emergency hazardous chemical releases
- Treatment technologies, sampling plans, and contaminant assessment
- Technical review for remedial and removal technology, safety, and preparedness
- Hazardous Materials Incident Response Training Program
- Site-safety plans, personnel protection, and safety

Health and Risk Assessment Technical Support Center
Environmental Criteria and Assessment Office-Cincinnati (ECAO-Cin)

Contact: Pei Fung-Hurst
FTS 684-7534 or (513) 569-7534

ECAO, in Cincinnati, Ohio, provides rapid turnaround support in the assessment of Superfund health and risk issues. The Center at ECAO-Cin:

- Provides chemical-specific health information
- Answers questions on the *Risk Assessment Guidance for Superfund (RAGS) Human Health Evaluation Manual*
- Develops interim and default approaches for issues related to risk assessment for Superfund sites
- Reviews site-specific Superfund risk assessments
- Develops, in cooperation with Superfund staff, site-specific and health-based trigger or cleanup levels for a contaminant
- Assists Regions in the identification of surrogate cleanup levels based on risk to human health

Engineering and Treatment Technical Support Center
Risk Reduction Engineering Laboratory, Cincinnati (RREL)

(see description on page 5)

Ground-Water and Engineering Technical Support Forums

Technical Support Forums are comprised of one or more technical specialists, RPMs, or OSCs from each of EPA's ten Regions. Two Forums have been established to date: *Ground-Water Fate and Transport*, and *Engineering*. Forum members provide information to OSCs and RPMs in their Regions regarding TSP efforts, research undertaken by the Centers, and problems and successes experienced by other Regions, including the application of remedial technologies at Superfund sites. Forum members convene by telephone monthly and meet twice each year. Forum members:

- Channel communications among the Regions, TSCs, headquarters personnel, and existing EPA technical programs
- Increase the transfer of information among the Centers and the Regions
- Act as a technical resource to the Regions and the Centers
- Route technical assistance information to Regional colleagues

Consult Appendix A, Regional Contacts, for the names and numbers of the Forum Members in your Region.

Engineering Programs and Treatability Studies

Ben Blaney: FTS 648-7406 or (513) 569-7406

EPA's Risk Reduction Engineering Laboratory offers the Regions three engineering technical assistance programs:

- Engineering and Treatment Technical Support Center
- Treatability Assistance Program (TAP)
- Superfund Technology Assistance Response Team (START)

The Engineering and Treatment Technical Support Center and the Superfund Technology Assistance Response Team (START) both handle site-specific remediation engineering problems for RPMs. The Treatability Assistance Program is intended to enhance RPMs' knowledge of treatment technologies and the conduct of treatability studies through technology transfer activities and the augmentation of EPA's in-house treatability study capabilities.

RREL offers expertise in contaminant source control structures; materials handling and decontamination; treatment of soils, sludges, and sediments; and treatment of aqueous and organic liquids. The following are examples of the technical assistance that can be obtained through RREL:

- Review of treatability aspects of RI/FS
- Review of RI/FS treatability study workplans and final reports
- Oversight of RI/FS treatability studies
- Review of treatability RFPs
- Definition of alternative remedies
- Assistance with studies of innovative technologies
- Assistance in full-scale design and start-up

Engineering and Treatment Technical Support Center

The Engineering and Treatment Technical Support Center plans and conducts engineering research and development related to treatment of solid and hazardous wastes. The Center is intended to supply quick-response technical assistance on focused, site-specific problems.

Treatability Assistance Program

Laboratory in-house treatability study capabilities cover soils and liquid streams. There are facilities for solidification, incineration, and chemical treatment studies of soils and incineration and chemical/physical/biological treatment of liquids. Facilities for conducting studies of extraction and biological treatment of soils are being developed.

The Treatability Assistance Program offers the following types of technology transfer support:

- List of available contractors to perform treatability studies
- Generic and technology-specific treatability study protocols (in preparation)

- Comprehensive database of all aqueous treatability studies
- Brief Treatment Technology Bulletins describing the applicability of various technologies

To obtain any of these lists or documents, contact Joan Colson (FTS 684-7501 or (513) 569-7501).

Superfund Technology Assistance Response Team (START)

The Superfund Technology Assistance Response Team (START) team provides technical support on Superfund site remediation from initial site evaluation through post-ROD design phases of remedial actions. START provides a long-term commitment of ORD engineering expertise (from RI/FS work plan development through 30% remedial design) as part of the technical assistance team for remediation of a particular site. Sites to receive START assistance are identified by Regional management.

Toxics Integration Branch

David Bennett: FTS 475-9486 or (202) 475-9486

The Toxics Integration Branch (TIB) of the Office of Emergency and Remedial Response's Hazardous Site Evaluation Division coordinates development of Superfund guidance, databases, technical assistance networks and program Directives relating to the (1) conduct of baseline health and environmental risk assessment; (2) development of risk information for remedial alternatives; and (3) use of risk information in establishing remediation goals during the remedy selection process. In addition to providing guidance in the above areas, TIB can assist the Regions in resolving conflicts with the Agency for Toxic Substance and Disease Registry (ATSDR) and in developing risk-related training programs for Regional, state, or contractor staff. TIB has established a network of Regional Toxics Integration Coordinators that can assist program staff on related matters at the Regional level.

Consult Appendix A, Regional Contacts, for the Toxics Integration Coordinator in your Region.

Superfund Technical Liaison Program (STLP)

David Klauder: FTS 382-7667 or (202) 382-7667

An ORD Technical Liaison will be placed in the Hazardous Waste Management Division of interested Regions to serve as a source of ORD information and to offer suggestions as to which laboratory can provide assistance to Regional emergency response, removal and remedial, enforcement, and environmental services personnel. STLP representatives in the Regions serve as brokers of technical support services to put requesters in touch with technical information suppliers.

Consult Appendix A, Regional Contacts, for the Superfund Technical Liaison in your Region.

Air/Superfund Coordination Program

Joseph Padgett: FTS 629-5589 or (919) 541-5589

Regional Air Offices review RODs for air impacts due to remediation. The Air/Superfund Coordination program is designed to help RPMs design ways to mitigate air impacts at Superfund sites, provide Air Office liaisons to Regional Superfund offices, and provide technical assistance and recommendations.

The Air/Superfund Coordination Program offers:

- Direct support: site evaluation, remedy selection, modeling assistance, monitoring, air pollution control devices
- Support services: interprogram coordination, training, resolving interprogram issues
- National Technical Guidance Studies (NTGS) to improve quality and consistency of procedures and data collection. The four-volume set covers baseline air emissions, air emissions from remediation, modeling and monitoring protocols, air pathway analysis procedures, and remediation field support procedures.

Consult Appendix A, Regional Contacts, for the Air/Superfund Coordinator in your Region.

Chemical Assessment Desk (CAD)

Elaine Suriano: FTS 382-3544 or (202) 382-3544

The Chemical Assessment Desk, operated by the Office of Toxic Substances, provides technical consultation and information on chemical risk-related issues to EPA Program Offices, Regions, and State and local agencies.

CAD offers a single contact point to:

- Consult on risk assessment and risk management activities for chemicals that have been evaluated in the OTS Existing Chemical Program
- Obtain assistance in identifying risk assessment activities in other EPA offices and Federal agencies
- Obtain estimates of toxicity and environmental fate based on structure-activity relationships
- Help identify unpublished information submitted to OTS
- Obtain comments on technical aspects of non-OTS evaluations and risk assessments

Superfund Innovative Technology Evaluation (SITE) Program

John Martin: FTS 684-7758 or (513) 569-7758

The SITE Program supports development of technologies for assessing and treating waste from Superfund sites. The program provides an opportunity for commercial technology developers to demonstrate the capabilities of their technologies. EPA evaluates the technologies and provides an assessment of their potential for future application.

The SITE Program is made up of four components: the Demonstration Program, the Emerging Technologies Program, the Monitoring and Measurement Technologies Program, and Technology Transfer activities.

Each Region has a contact person that provides information on the SITE Program. Consult Appendix A, Regional Contacts, for the name and number of the contact in your Region. To propose a candidate demonstration site, contact either your Regional Contact or John Martin at the Risk Reduction Engineering Laboratory at the number above.

Technical reports describing completed demonstrations and general information may be obtained from the Center for Environmental Research (CERI) in Cincinnati, Ohio at FTS 684-7562 or (513) 569-7562. As of September, 1990, forty-three technologies have been selected for evaluation. Fourteen demonstrations have been completed, and eight final reports are available. In addition, updates to demonstrations are posted on the OSWER Electronic Bulletin Board. (See description on page 13.)

Bioremediation Field Initiative

Fran Kremer FTS 684-7346 or (513) 569-7346

OSWER and ORD have jointly instituted a Bioremediation Field Initiative to provide assistance to the Regions in conducting field tests and evaluations of bioremediation site cleanups in Superfund, RCRA, UST, and state non-NPL programs planned or in progress as of June, 1990. The initiative will be in effect for the next 18 to 24 months.

The initiative is designed to more fully document performance of full-scale field applications of bioremediation, provide technical assistance for sites in a feasibility or design stage (to facilitate treatability studies), and regularly provide the Regions with information on treatability studies, design, and full-scale operations of bioremediation projects in the Regions.

To request assistance at a Superfund site or obtain more information about on-going bioremediation projects in the field, contact Fran Kremer at the number above.

Automated Information Systems

1. **OSWER Electronic Bulletin Board (OSWER BBS)**
   Contact: Jim Cummings FTS 382-4686 or (202) 382-4686

   The OSWER Electronic Bulletin Board System (BBS) facilitates communication and the dissemination of information among EPA staff in Regional offices, headquarters, and research laboratories.

   To use the OSWER BBS you need a personal computer or terminal, a modem, and a communications program. To access the OSWER BBS, dial (301) 589-8366 after setting your CrossTalk parameters to 8 data bits, 1 stop bit, and no parity. Choose your own password, complete an on-line registration questionnaire and in 24 hours you'll be a registered user with full access to all features of the system. The BBS is available to EPA staff, current contractors, and State and Federal agency personnel.

   Major features of the OSWER BBS include:

   - Information Bulletins
   - Message Exchange
   - File Exchange
   - Technical Publication Ordering
   - On-line Databases and Directories

2. **RODS Database**
   Contact: RODS Information Hotline (202) 245-3770

   RODS is an automated database containing Superfund Records of Decision (ROD), which describe the planned course of action to clean up a site. The database, installed on a mainframe at EPA's National Computer Center in Research Triangle Park, allows searching for selected information from ROD documents or NTIS Abstracts. Access is via modem from a PC.

3. **Alternative Treatment Technology Information Center (ATTIC)**
   Contact: Myles Morse FTS 475-7161 or (202) 475-7161

   The ATTIC system is designed to provide technical information on alternative methods of hazardous waste treatment. ATTIC is available through any modem-equipped IBM compatible PC using standard communications software. The on-line system allows the experienced user to conduct searches and download technical information without going through the ATTIC system operator. The ATTIC system operator is available to respond to information requests from users that do not have communications capabilities or do not wish to conduct their own searches.

The core of the ATTIC system is the ATTIC Database, a user-searchable, keyword-driven system that contains technical information in the form of abstracts or report summaries from a variety of sources including the SITE Program, States, industry, NATO, DOD/DOE, RODs, and Treatability Studies. The two other online user-searchable databases in ATTIC are the RREL Water Treatability Database and Technical Assistance Directory.

Other databases contained in the ATTIC system that can be searched by the System Operator upon request include:

- RSKERL Soil Transport and Fate Database
- EPA Library Hazardous Waste Collection Database
- Cost of Remedial Action Model
- Geophysics Advisor Expert System
- RODS Database

Access to the on-line ATTIC system is controlled by a log-in ID and password available from the ATTIC system operator. Technical information requests can also be made directly to the system operator. The ATTIC system operator can be reached at (301) 816-9153.

4. **Expert Resources Inventory System (ERIS)**
Contact: Kurt Lamber FTS 398-8624 or (703) 308-8624

The Expert Resource Inventory System, maintained by the Office of Waste Programs Enforcement (OWPE), is a searchable database that contains resumes in summary form and information on qualifications, area of expertise, and previous experience of specialists available as expert witnesses or consultants to support hazardous waste enforcement actions. The database may be accessed by EPA and Department of Justice staff upon request. The database has been classified as "enforcement confidential" and is protected under the Privacy Act of 1974. Hard copies of complete resumes and other supporting documents are maintained in a parallel file in OWPE. Plans are underway to make ERIS available to authorized users on the OSWER Electronic Bulletin Board.

5. **Hazardous Waste Collection Database (HWCD)**
Contact: Liliana Puzick FTS 382-2977 or (202) 382-2977

The HWCD is a bibliographic database containing abstracts of EPA and other government agency reports, commercial books, policy and guidance directives, legislation, and regulations concerning hazardous waste that is searchable by subject. A database thesaurus is available to aid users in designing efficient searches.

6. **Integrated Risk Information System (IRIS)**
Contact: Linda Tuxen FTS 382-5949 or (202) 382-5949

IRIS contains health risk data, bibliographic and textual information on risk management,

water quality criteria, and drinking water standards. It is available on-line through EPA's electronic mail system (E-MAIL).

To access IRIS through E-MAIL, after signing on, type "IRIS" at the ">" prompt.

7. **Center for Exposure Assessment Modeling (CEAM)**
Contact: Bob Ambrose FTS 250-3130 or (404) 546-3130
CEAM BBS: FTS 250-3402 or (404) 546-3402

CEAM offers state-of-the-art exposure assessment technology and models for environmental risk-based decisions. CEAM provides:

- Assistance in site-specific problem definition and predictive techniques for assessing metals and chemical pathways
- Training and assistance to Regional Superfund staff in exposure and ecorisk assessments
- Distribution of models and databases
- Expert witness testimony and exposure calculations and assessments for especially difficult or unusual scenarios, peer review of exposure and ecorisk assessments

8. **Subsurface Remediation Information Clearinghouse**
Contact: John Matthews FTS 743-2233 or (405) 332-8800

See description on page 2.

9. **International Ground-Water Modeling Center (IGWMC)**
Contact: Cathy Mulberry at (317) 283-9458

See description on page 2.

10. **Commercial Databases** searchable free of charge by EPA HQ and Regional Librarians: DIALOG, Chemical Information System, and BRS Search Services are examples of commercial databases that abstract information relevant to EPA's hazardous and solid waste programs. Other commercial databases, including legal systems, are also available. For more information, contact your Regional librarian.

Publications

1. ***Catalog of Superfund Directives*** OSWER Directive 9200.7-01 - July 1988 (61 pages) The Catalog provides a reference to policy, procedural, and technical directives governing the Superfund program. Regular supplements are planned. Publications abstracted must be obtained from the issuing office. Regional and HQ libraries also have copies. Copies of the Catalog may be obtained from the Superfund Docket at (202) 382-6940 or FTS 382-6940.

2. ***OSWER Directives - System Catalog*** OSWER Directive 9013.15-3D (30 pages) Provides a list of OSWER Directives published through June 1988.

   Each Region also has an OSWER Directive Coordinator. Consult Appendix A, Regional Contacts, for the name and number of the Directives Coordinator in your Region.

3. ***Superfund Risk Assessment Information Directory*** OSWER Directive 9285.6-1 (202 pages). Publication number EPA/540/1-86/061

   The directory identifies and describes sources of information useful in conducting risk assessments. The directory covers sources of information to aid in hazard identification, dose-response assessments, exposure assessments, and risk characterization. Available from CERI (513) 569-7562 or FTS 684-7562.

4. ***Annotated Technical Reference for Hazardous Waste Sites***
   Contact: Office of Waste Programs Enforcement (OWPE)
   FTS 398-8622 or (703) 308-8622

   This reference provides information on 14 common site types: asbestos, battery recycling/lead, dioxins, landfills, metals, mining wastes, mixed waste, multi-source ground water, munitions, PCBs, pesticides, plating, solvents, and wood preserving. Information includes ARARs, risk assessments, and summaries of typical site characteristics. The reference provides access to technical expertise through lists of Regional technical experts and technical references. The current version is considered a draft and is being updated.

5. ***CERCLA Administrative Records: Compendium of Frequently Used Guidance Documents in Selecting Response Actions***
   Contact: Office of Waste Programs Enforcement (OWPE)
   CERCLA Guidance and Oversight Branch FTS 475-6770 or (202) 475-6770
   or Regional Administrative Records Coordinator

   This reference (sent to Regions May 22, 1989) serves as a central library of guidance documents in each Region. This also saves resources by avoiding the need to copy such documents for each administrative record.

6. ***Selected Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation*** Publication Number EPA/540/8-90/003

   A bibliography of international surveys, technology survey reports, treatability studies, guidance documents, technical support documents, reports on ground water, incineration, solidification, biological treatment, physical/chemical treatment, and databases. Available from CERI at FTS 684-7562 or (513) 569-7562.

7. ***SITE Program Fact Sheet*** OSWER Directive 9380.1-03FS July 1990 (4 pages)

   A concise description of the Superfund Innovative Technology Evaluation (SITE) Program including a program overview, highlights and progress, technology transfer activities and publications, and Regional contacts. Available from CERI at FTS 684-7562 or (513) 569-7562.

Notes

Other Sources of Information

1. **National Association of RPMs**
   Contact: Steve Veale, EPA Region VI, FTS 255-6715 or (214) 655-6715

   NARPM is a professional association representing approximately 400 EPA RPMs. An RPM Directory listing RPM name, phone, and professional information has been published to facilitate technical exchange among Regional staff. The NARPM Executive Council has representatives in each Region.

   Consult Appendix A, Regional Contacts, for the name and number of the NARPM Representative in your Region.

2. **National OSC Association**
   Contact: Bill Simes, EPA Region V, FTS 886-6236 or (312) 886-6236

   This is a professional association for the approximately 130 EPA On-Scene Coordinators. A directory listing OSCs by Region and by technical specialty is available by calling Bill Simes at the above number. Consult Appendix A, Regional Contacts, for the name and number of the NOSCA Representative in your Region.

3. **Regional Response and Removal Coordinators**

   Regional Coordinators for response and removal, located at Headquarters, provide the Regions with on-going support from early response and RI/FS scoping through post-ROD activities, and provide a national quality assurance program.

   Consult Appendix B, Headquarters Contacts, for the name and number of the Coordinator for your Region.

4. **Regional ARARs Coordinators**

   Regional ARARs Coordinators communicate Regional questions on ARARs issues to Headquarters, attend a monthly teleconference with Headquarters staff, and keep the Regions informed on latest national policies.

   Consult Appendix A, Regional Office Contacts, for the Coordinator in your Region.

5. **Federal Facilities Coordinators**

Federal Facility Coordinators provide policy information and guidance documents to Regional Staff concerned with hazardous waste sites at DOD, DOE, and other Federal facilities.

Consult Appendix A, Regional Contacts, for the Federal Facility Coordinator in your Region.

6. **Center for Environmental Research Information (CERI)**
Contact: Clarence Clemmons FTS 684-7358 or (513) 569-7358
Electronic Bulletin Board: FTS 684-7610 or (513) 569-7610

CERI develops publications, expert systems, and computer-assisted training and conducts training seminars in support of EPA programs including Superfund. CERI operates an electronic bulletin board with a database of over 15,000 searchable abstracts of all ORD publications.

7. **Hazardous Substance Research Centers (HSRC)**
Contact: Karen Morehouse FTS 382-5750 or (202) 382-5750

Five university-based centers, each serving a pair of Regions, focus on problems of their geographic regions with emphasis in a specific area of research. The Centers perform long-term and short-term research on all aspects of hazardous substance generation, management, use, transportation, and disposal. The Centers are committed to technology transfer, and are overseen by the Training and Technology Transfer Advisory Committee (TTAC).

Regional Contacts and areas of expertise:

- Region Pair 1 & 2.
  Contact: Patricia Meany FTS 835-3355 or (617) 565-3355
  Emphasis: ground-water remediation, pretreatment of industrial wastes, incineration
  Universities: New Jersey Institute of Technology, Massachusetts Institute of Technology, Princeton University, Rutgers University, Stevens Institute of Technology, Tufts University, and University of Medicine and Dentistry of New Jersey

- Region Pair 3 & 5.
  Contact: Harry Harbold FTS 597-9492 or (215) 597-9492
  Emphasis: biological degradation processes for organic substances
  Universities: University of Michigan, Howard University, and Michigan State University

- Region Pair 4 & 6.
  Contact: Norman Dyer FTS 255-2252 or (214) 655-2252
  Emphasis: waste minimization and waste management
  Universities: North Carolina State University, University of North Carolina-Chapel Hill, and Texas A&M University

- Region Pair 7 & 8.
  Contact: Jerry Anderson FTS 276-7372 or (913) 551-7372
  Emphasis: metal recovery and recovery of organic wastes
  Universities: Kansas State University, Montana State University, University of Iowa, University of Missouri, University of Montana, University of Nebraska, and University of Utah

- Region Pair 9 & 10.
  Contact: Don White FTS 484-1918 or (415) 744-1918
  Emphasis: physical, chemical, and biological treatment of surface and subsurface contaminants
  Universities: Stanford University and Oregon State University

8. Specialty Area Contacts

Certain technical and programmatic topic areas are of continuing interest to Regional staff. While the Regional Coordinators in Appendix B provide a principal point of contact, OERR has developed a list of Specialty Area Contacts who have more detailed knowledge of specific subjects that arise during site cleanup activities.

Consult Appendix B, Headquarters Contacts, for the name and number of the contact for your area of interest.

Notes

APPENDIX A: Regional Contacts

Region I

For commercial numbers: FTS 835 = (617) 565 and FTS 833 = (617) 573

Ground Water Forum Members (p. 4)	Steve Mangion	FTS 833-1718
	Dick Willey	FTS 833-1639
Engineering Forum Members (p. 4)	Yoon-Jean Choi	FTS 833-9633
	Michael Jasinski	FTS 833-5786
	Lynne Fratus	FTS 833-9634
Toxics Integration Coordinator (p. 7)	Sarah Levinson	FTS 833-1504
Air/SF Coordinator (p. 9)	Rose Toscano	FTS 835-3280
SITE Program Contact (p. 11)	Diana King	FTS 833-1676
OSWER Directives Coordinator (p. 16)	Francine Picardo	FTS 833-1700
NARPM Representative (p. 19)	Lynne Fratus	FTS 833-9634
NOSCA Representative (p. 19)	Paul Groulx	(617) 860-4300
ARARs Coordinator (p. 19)	Dennis Huebner	(617) 573-9610
	Dick Boynton	FTS 833-9631
	Bill Walsh-Roglaski	FTS 833-1334
Federal Facility Coordinator (p. 20)	Clara Chow	FTS 835-3287
Hazardous Substance Research Center Contact (p. 20)	Patricia Meany	FTS 835-3355

Region II

For commercial numbers: FTS 264 = (212) 264, FTS 835 = (617) 565, and FTS 340 = (201) 321

Ground Water Forum Members (p. 4)	Kevin Willis	FTS 264-1784
	Frederick Luckey	FTS 264-6786
	Alison Hess	FTS 264-6040
Engineering Forum Members (p. 4)	Richard Kaplan	FTS 264-3819
	Agram Fayon	FTS 264-4706
Toxics Integration Coordinator (p. 7)	Peter Grevatt	FTS 264-8775
Air/SF Coordinator (p. 9)	Grace Musumeci	FTS 264-2517
SITE Program Contact (p. 11)	Peter D. Moss	FTS 264-4703
OSWER Directives Coordinator (p. 16)	Leslie Peterson	FTS 264-9251
NARPM Representative (p. 19)	Damian Duda	FTS 264-9589
NOSCA Representative (p. 19)	Douglas Kodama	FTS 340-6905
ARARs Coordinator (p. 19)	Vince Pitruzzello	FTS 264-3984
Federal Facility Coordinator (p. 20)	Robert Hargrove	FTS 264-1892
Hazardous Substance Research Center Contact (p. 20)	Patricia Meany	FTS 835-3355

Region III

For commercial numbers: FTS 597 = (215) 597

Ground Water Forum Members (p. 4)	Kathy Davies Phil Rotstein	FTS 597-6488 FTS 597-8185
Engineering Forum Members (p. 4)	Paul Leonard	FTS 597-1286
Toxics Integration Coordinator (p. 7)	Richard Brunker	FTS 597-0804
Air/SF Coordinator (p. 9)	Donna Abrams	FTS 597-9134
SITE Program Contact (p. 11)	Paul Leonard	FTS 597-1286
OSWER Directives Coordinator (p. 16)	Donna Sutsko	FTS 597-6182
NARPM Representative (p. 19)	Terry Stilman	FTS 597-0984
NOSCA Representative (p. 19)	David Wright	FTS 597-7915
ARARs Coordinator (p. 19)	Bonita Guy Gross Marty Powell	FTS 597-9023 FTS 597-8170
Federal Facility Coordinator (p. 20)	Lorraine Urbiet	FTS 597-9302
Hazardous Substance Research Center Contact (p. 20)	Harry Harbold	FTS 597-9492

Region IV

For commercial numbers: FTS 257 = (404) 347 and FTS 255 = (214) 655

Ground Water Forum Members (p. 4)	(vacant)	
Engineering Forum Members (p. 4)	Jim Orban Jon Bornholm	FTS 257-2643 FTS 257-7791
Toxics Integration Coordinator (p. 7)	Elmer Akin	FTS 257-1586
Superfund Technical Liaison (p. 8)	John Risher	FTS 257-1586
Air/SF Coordinator (p. 9)	Stuart Perry	FTS 257-2864
SITE Program Contact (p. 11)	Elmer Akin	FTS 257-1586
OSWER Directives Coordinator (p. 16)	Rose Gray	FTS 257-3454
NARPM Representative (p. 19)	David Abbott	FTS 257-2643
NOSCA Representative (p. 19)	Arthur Smith	FTS 257-3931
ARARs Coordinator (p. 19)	Jim Orban	FTS 257-2643
Federal Facility Coordinator (p. 20)	Art Linton	FTS 257-3776
Hazardous Substance Research Center Contact (p. 20)	Norman Dyer	FTS 255-2252

Region V

For commercial numbers: FTS 886 = (312) 886, FTS 353 = (312) 353, and FTS 597 = (215) 597

Ground Water Forum Members (p. 4)	Doug Yeskis Luanne Vanderpool	FTS 886-0408 FTS 353-9296
Engineering Forum Members (p. 4)	Anthony Holoska Kaushal Khanna	FTS 886-7503 FTS 886-3011
Toxics Integration Coordinator (p. 7)	Steve Ostrodka	FTS 886-3011
Air/SF Coordinator (p. 9)	Xuan-Mai Trang	FTS 886-6043
SITE Program Contact (p. 11)	Steve Ostrodka	FTS 886-3011
OSWER Directives Coordinator (p. 16)	Denise Reape	FTS 353-8987
NARPM Representative (p. 19)	Ken Tindall	FTS 886-9895
NOSCA Representative (p. 19)	Leonard Zintak	FTS 886-1961
ARARs Coordinator (p. 19)	Jon Dikinis Judy Kleiman Jim Mayka	FTS 886-7572 FTS 886-1482 FTS 353-9229
Federal Facility Coordinator (p. 20)	Elmer Shannon	FTS 886-7342
Hazardous Substance Research Center Contact (p. 20)	Harry Harbold	FTS 597-9492

Region VI

For commercial numbers: FTS 255 = (214) 655

Ground Water Forum Members (p. 4)	Ruth Izraeli	FTS 255-6735
Engineering Forum Member (p. 4)	Deborah Griswold Sherry Fuerst	FTS 255-6715 FTS 255-2198
Toxics Integration Coordinator (p. 7)	Jon Rauscher	FTS 255-2198
Air/SF Coordinator (p. 9)	Mark Hansen	FTS 255-7223
SITE Program Contact (p. 11)	Sherry Fuerst	FTS 255-2197
OSWER Directives Coordinator (p. 16)	Helen Newman	FTS 255-6720
NARPM Representative (p. 19)	Steve Veale	FTS 255-6715
NOSCA Representative (p. 19)	Craig Carlton	FTS 255-2270
ARARs Coordinator (p. 19)	Sherry Fuerst	FTS 255-2197
Federal Facility Coordinator (p. 20)	Jim Highland	FTS 225-2260
Hazardous Substance Research Center Contact (p. 20)	Norman Dyer	FTS 255-2252

Region VII

For commercial numbers: FTS 757 = (913) 236 and FTS 276 = (913) 551

Ground Water Forum Members (p. 4)	Steve Kinser	FTS 276-7728
Engineering Forum Members (p. 4)	Steve Kovac	FTS 276-7698
Toxics Integration Coordinator (p. 7)	Dave Crawford	FTS 276-7702
Air/SF Coordinator (p. 9)	Wayne Kaiser	FTS 276-7603
SITE Program Contact (p. 11)	Dana Trugley	FTS 276-7705
OSWER Directives Coordinator (p. 16)	Barry Thierer	FTS 276-7515
NARPM Representative (p. 19)	Steve Kovac	FTS 276-7698
NOSCA Representative (p. 19)	George Hess	FTS 757-3888
ARARs Coordinator (p. 19)	Bob Feild	FTS 276-7697
Federal Facility Coordinator (p. 20)	Craig Burnstein	FTS 276-7688
Hazardous Substance Research Center Contact (p. 20)	Jerry Anderson	FTS 276-7372

Region VIII

For commercial numbers: FTS 330 = (303) 294, FTS 564 = (303) 293, and FTS 276 = (913) 551

Ground Water Forum Members (p. 4)	Paul Osborne Darcy Campbell	FTS 330-1418 FTS 330-7596
Engineering Forum Members (p. 4)	Henry Schroeder Gerry Snyder	FTS 330-7074 FTS 564-7504
Toxics Integration Coordinator (p. 7)	Chris Weis	FTS 330-7655
Superfund Technical Liaison (p. 8)	Bob Stone	FTS 330-7597
Air/SF Coordinator (p. 9)	Norm Huey	FTS 330-1760
SITE Program Contact (p. 11)	Gerry Snyder	FTS 564-7504
OSWER Directives Coordinator (p. 16)	Carol Macy	FTS 330-7038
NARPM Representative (p. 19)	Tim Rehder	FTS 330-1529
NOSCA Representative (p. 19)	Pete Stevenson	FTS 330-7064
ARARs Coordinator (p. 19)	Jonah Staller	FTS 330-7548
Federal Facility Coordinator (p. 20)	Elmer Chenault	FTS 330-1644
Hazardous Substance Research Center Contact (p. 20)	Jerry Anderson	FTS 276-7372

Region IX

For commercial numbers: FTS 556 = (415) 556 and FTS 484 = (415) 744

Ground Water Forum Members (p. 4)	Herb Levine Richard Frietas	FTS 484-1914 FTS 484-1914
Engineering Forum Members (p. 4)	Ken Erickson	FTS 484-1067
Toxics Integration Coordinator (p. 7)	Gerald Hiatt	FTS 484-1730
Air/SF Coordinator (p. 9)	Mike Stenberg	FTS 556-5271
SITE Program Contact (p. 11)	John Blevins	FTS 484-9103
OSWER Directives Coordinator (p. 16)	Deborra Samuels	FTS 556-6596
NARPM Representative (p. 19)	Alisa Greene Mike Montgomery	FTS 484-1890 FTS 484-1996
NOSCA Representative (p. 19)	Brad Shipley	FTS 484-1026
ARARs Coordinator (p. 19)	Jean Rice	FTS 556-5895
Federal Facility Coordinator (p. 20)	Rachel Dagovitz	FTS 556-5102
Hazardous Substance Research Center Contact (p. 20)	Don White	FTS 484-1918

Region X

For commercial numbers: FTS 399 = (206) 442 and FTS 484 = (415) 744

Ground Water Forum Members (p. 4)	Rene Fuentes Bernard Zavala	FTS 399-1599 FTS 399-1562
Engineering Forum Members (p. 4)	John Barich Bob Stamnes	FTS 399-8562 FTS 399-8562
Toxics Integration Coordinator (p. 7)	Patricia Cirone	FTS 399-1597
Air/SF Coordinator (p. 9)	Elizabeth Waddell	FTS 399-8578
SITE Program Contact (p. 11)	John Barich	FTS 399-8562
OSWER Directives Coordinator (p. 16)	Jayne Carlin	FTS 399-2852
NARPM Representative (p. 19)	Kathy Davidson	FTS 399-1088
NOSCA Representative (p. 19)	John Sainsbury	FTS 399-1263
ARARs Coordinator (p. 19)	Kathy Davidson	FTS 399-1088
Federal Facility Coordinators (p. 20)	Clark Smith	FTS 399-1327
Hazardous Substance Research Center Contact (p. 20)	Don White	FTS 484-1918

APPENDIX B: Headquarters Contacts

For commercial numbers, FTS 382 = (202) 382, FTS 475 = (202) 475, and FTS 398 = (703) 308

Fund Lead: RI/FS and ROD

Region	Name	FTS No.
I	Jennifer Haley	398-8363
II	Alison Barry	398-8366
III	Sharon Frey	398-8367
IV	Tish Zimmerman	398-8370
V	Andrea McLaughlin	398-8365
	Sandra Panetta	398-8364
VI	Robin Anderson	398-8371
VII	Tish Zimmerman	398-8370
VIII	Steve Golian	398-8360
IX	David Cooper	398-8361
X	Steve Golian	398-8360

Fund Lead: Removal and Expedited Response Action

Region	Name	FTS No.
I	Terry Eby	382-7734
II	Mark Mjoness	382-2206
III	Gregory Weigel	382-2196
IV	Gregory Weigel	382-2196
V	Terri Johnson	382-2205
VI	Jennifer Maloney	382-2184
VII	Terri Johnson	382-2205
VIII	Jennifer Maloney	382-2184
IV	Terri Johnson	382-2205
X	Terry Eby	382-7734

Enforcement Lead: Removal, RI/FS, ROD, RD/RA, Negotiations, Litigation

Region	Name	FTS No.
I	Tai Ming Chang	475-8259
II	Bruce Kulpan	475-7283
	Lance Elson	382-5617
III	Deborah Pernice	382-2016
	Kathryn Boyle	475-9317
IV	Neilima Senjalia	475-7027
	Darlene Boerlage	382-4819
V	Kurt Lamber	382-4848
	Ernie Watkins	382-4837
	Trish Gowland	382-7790
VI	Filomena Chau	475-7082
	Debby Swichkow	475-7026
VII	Jack Schad	382-4831
VIII	Joe Tieger	475-8372
	Lori Boughton	382-7789
IX	Ross Natoli	382-2063
	Rick Popino	382-3401
X	Joe Tieger	475-8372

Fund and Enforcement Lead: Design and Construction

Region	Name	FTS No.
I	JoAnn Griffith	398-8353
II	Joe Cocalis	398-8356
III	Bill Zobel	398-8354
IV	Ken Skahn	398-8355
V	Tracy Loy	398-8349
VI	Ed Hanlon	398-8352
VII	Ken Skahn	398-8355
VIII	Ben Hamm	398-8347
IX	Ed Hanlon	398-8352
X	Ed Hanlon	398-8352

Specialty Area Contacts

Topic	Name	FTS No.
ARARS (Application of)	Rhea Cohen	382-2182
ARARS (Land Disposal Restrictions)	Steve Golian	398-8360
ARARS (Delisting, No migration)	Sharon Frey	398-8367
ASTSWMO	Ann McDonough	398-8339
Bureau of Reclamation, ARCS (Change orders, A/E Liability)	Tracy Loy	398-8349
Community Relations	Melissa Shapiro	398-8340
Completion/Deletion	Chris Watling	398-8348
Cooperative Agreements, SSCs, Core programs	Jan Baker	398-8328
CORA Model	Kirby Biggs	475-9756
Corps of Engineers	Bill Zobel	398-8354
Design of Containment Remedies	Ken Skahn	398-8355
Five Year Reviews	Bill Ross	398-8335
Ground Water Remediation	Jennifer Haley	398-8363
Health and Safety	Joe Cocalis	398-8356
Incineration	Robin Anderson	398-8371
Indemnification (State Contractors)	Hugo Fleischman	398-8336
Indemnification (ARCs, REM)	Ben Hamm	398-8347
Indian Issues	Jan Baker	398-8328
Labor Rates/Cost Estimates	Tom Whalen	398-8345
Mining	Steve Golian	398-8360
Multisource Ground Water	Deborah McKie	398-8372
Municipal Landfills	Sue Cange	398-8362
Natural Resource Damage	Bill Ross	398-8335
PCBs	Jennifer Haley	398-8363
Preauthorization/Claims	Bill Ross	398-8335
PRP Oversight for RD/RA	Ed Hanlon	398-8352
Real Estate	JoAnn Griffith	398-8353
Risk Assessment	Bruce Means	382-2201
Selection of Remedy	David Cooper	398-8361
Soil/Ground Water Modeling	Alison Barry	398-8366
Technical Assistance Grants (TAG)	Linda Ross	398-8342
Treatability Studies	Robin Anderson	398-8371

Suggestions

If your favorite sources of technical information are not in this directory, or if you are often in need of information and don't know how to find it, please make a note on this page, tear it out, fold and tape it to show the pre-printed address label, add postage, and drop it in the mail.

Please also use this form to alert us to any names or numbers in this directory that you know are out of date. Thank you.

fold here

Richard Steimle
Technology Innovation Office (OS-110)
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

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United States Environmental Protection Agency | Office of Solid Waste and Emergency Response | Technology Innovation Office

EPA Vendor Information System for Innovative Treatment Technologies (VISITT)

Progress Report – June 1991

INTRODUCTION TO VISITT

The Vendor Information System for Innovative Treatment Technologies (VISITT) is a new database being developed by EPA to provide current information on innovative treatment. VISITT will contain technology information submitted by developers, manufacturers, and suppliers of innovative treatment technology equipment and services. The database will provide a means for innovative technology vendors to make their products and capabilities known. The system is being designed for hazardous waste cleanup professionals to learn about the applications and performance of these new technologies.

TECHNOLOGIES INCLUDED

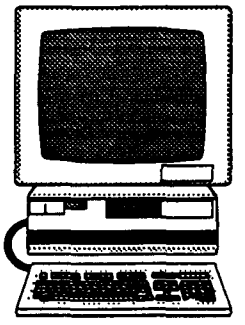
VISITT will contain information on vendors of *innovative* technologies to treat soils, sludges, sediments, and ground water in situ. Examples of technologies included are soil washing, thermal desorption, bioremediation, solvent extraction, and in situ vitrification. The database will not include more established technologies—incineration, solidification/stabilization, and pump-and-treat ground water. Technologies may be at bench, pilot, or full scale.

INFORMATION INCLUDED

Each vendor file in VISITT will include company information (company name, address, contacts, and phone number), a technology description, technology advantages and limitations, and applicable media, wastes, and contaminants. The vendor may provide additional information on technologies at the pilot or full scale, including:

- Performance data
- Waste limitations
- Unit costs and factors impacting cost
- Available hardware/capacity
- Project names and contacts
- Permits obtained
- Treatability study capabilities
- References

FEATURES OF VISITT



Some of the features VISITT will offer include the ability to:

- Enter a waste description to identify innovative technologies that treat such wastes
- Enter a specific technology to identify available vendors
- Enter a site name to locate any vendors that may have conducted treatability studies or cleanups at that site
- View the information on the screen
- Print complete vendor/technology information

STATUS

EPA is now accepting information from technology companies to be included in the database. EPA will advertise the information request in the U.S. Commerce Department's *Commerce Business Daily*, trade journals, and conferences. The first release of the database is scheduled for early 1992. VISITT will be updated at least annually.

HOW TO SUBMIT TECHNOLOGY INFORMATION

The Vendor Information Form is now available to treatment vendors who would like to be included in VISITT. Information submitted to EPA by September 30, 1991 will be considered for inclusion in the first release of VISITT in early 1992.

The Vendor Information Form (EPA/540/2-91/011) is available from EPA/ORD Publications at (513) 569-7562.

HOW TO RECEIVE THE VISITT DATABASE

If you would like to order VISITT when it becomes available, complete the form below and send to:

VISITT Database
PRC Environmental Management, Inc.
1505 Planning Research Drive
McLean, VA 22102

Please place me on the mailing list to receive information on the Vendor Information System for Innovative Treatment Technologies (VISITT) when it becomes available.

Name _____ Company _____

Address _____ City _____ State _____ Zip Code _____

Development Of An Alternative Treatment Technology Data Base And Information Center

William Sproat
James Pennington
Technical Resources, Inc.
Rockville, Maryland

Michael Mastracci
Myles Morse
U.S. Environmental Protection Agency
Washington, D.C.

ABSTRACT

The U.S. EPA's Office of Research and Development (ORD), supported by Technical Resources, Inc., (TRI) of Rockville, Maryland, has created the Alternative Treatment Technology Information Center (ATTIC). ATTIC is a comprehensive, automated information retrieval system that integrates hazardous waste data into a centralized, searchable resource. The intent of ATTIC is provide the user community with technical data and information on available innovative treatment technologies and to serve as an initial decision support system. Since ATTIC functions as a focal point for users, it facilitates the sharing of information within the user community and creates an effective network of individuals and organizations involved in hazardous waste site remediation.

INTRODUCTION

Since August 1987, the U.S. EPA's Office of Environmental Engineering and Technology Demonstration (OEETD) and Office of Solid Waste and Emergency Response (OSWER) have been testing a prototype clearinghouse for information on alternative treatment technologies for hazardous waste. This clearinghouse which is mandated by SARA Section 209 (b)(8), is the primary technology transfer mechanism for disseminating information concerning the Superfund Innovative Technology Evaluation (SITE) program. This clearinghouse mechanism has evolved into the Alternative Treatment Technology Information Center (ATTIC), a comprehensive computer-based information retrieval system that provides data and technical information on alternative methods of hazardous waste treatment.

The information contained in ATTIC consists of a wide variety of data obtained from Federal and state agencies. The core of the ATTIC system is the ATTIC Data Base which contains abstracts and executive summaries from over 1200 technical documents and reports. Information in the ATTIC Data Base has been obtained from the following sources

- The Superfund Innovative Technology Evaluation (SITE) Program
- California Summary of Treatment Technology Demonstration Projects
- Data Collected for the Summary of Treatment Technology Effectiveness for Contaminated Soil
- NATO International Data
- Innovative Technologies Program Data
- Removal Sites Technologies Data
- RCRA Delisting Actions
- USATHAMA Installation Restoration and Hazardous Waste Control Technologies
- Records of Decision (RODS from 1988 on)
- Treatability Studies

In addition, the ATTIC system contains resident data bases that have been previously developed, as well as access to on-line commercial data bases. The ATTIC resident data bases include

- RREL Water Treatability Database
- RSKERL Soil Transport and Fate Database
- EPA Library Hazardous Waste Collection
- ORD Technical Assistance Directory
- Cost of Remedial Action (CORA) Model
- Geophysics Advisor Expert System
- On-line Resources
  - Computerized On-Line Information System (COLIS)
  - OSWER Bulletin Board
  - Dialcom
  - NTIS
  - RODS Data Base

DISCUSSION

Conceptual development of the ATTIC system began in February 1988 with a series of meetings between TRI and OEETD staff in Washington, D.C. Since the basic concept of the ATTIC system was to provide support and assistance to the Regional Offices, input was solicited from various Regions and states, in particular Region 3, to determine the type and kind of information that would be most useful to the Regional staff. Based on his input, a prototype version of the ATTIC system was developed in Aug., 1988 and demonstrated to OEETD staff and to staff members in Region 3. Following subsequent modifications, data entry began in Dec. 1988. After a sufficient number of technical documents were collected, evaluated and abstracted, the ATTIC system was presented to Region 3 for data (pilot) testing in April 1989

The beta test of the ATTIC system took place in the Hazardous Waste Management Division (HWMD) in Region III.[1] The beta test was considered a success and the HWMD ATTIC users were unanimous in their opinion that the system was extremely useful because the information contained was current and of high quality

Following the beta test, TRI and OEETD felt that the ATTIC system was in a position to become operational on a limited basis On May 8, 1988, the ATTIC system became operational and the user community could access the system through the system operator The ATTIC system was designed to provide information on hazardous waste treatment to a user community made up of the U S EPA Headquarters and Regional staff, participating state environmental agencies and the numerous remediation contractors. The system operator would work with the individual user to determine the type of information desired and tailor the search with specific key words using standard boolean logic When a search had been completed, abstracts of all reports identified were

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submitted to the user through any one of several methods including fax and overnight mail. The user could then determine from the abstracts which documents would be most applicable to the user's information needs.

Since ATTIC became operational, more than 250 requests for information have been received by the system operator. Approximately 40% of the information requests have been from the U.S. EPA regional staff, 30% from ARCS contractors and 30% from various other U.S. EPA contractors. In June 1989, an alternative method for accessing one portion of the ATTIC system was made available to the user community. The ATTIC Data Base component of the ATTIC system was made available in a disk-based format using 5.25- or 3.5-inch diskettes that operate on any IBM compatible PC. While the ATTIC Data Base component of the ATTIC system is updated weekly, the disk-based version of the ATTIC Data Base is only updated quarterly. Since the introduction of the disk-based version, over 800 copies of the data base have been distributed to the user community.

Faced with the logistical problem of updating 800-plus diskettes every quarter, TRI and OEETD began development of an on-line operation for the ATTIC system. On Dec. 1, 1989, the ATTIC Data Base component of the ATTIC system became available to the user community through any modem-equipped IBM-PC compatible machine. Using standard communications software, members of the user community were then able to access the ATTIC system, conduct searches and download technical information without going through the ATTIC system operator. The ATTIC system operator continued to be available to respond to information requests from members of the user community that did not have communications capabilities or did not wish to conduct their own searches. As other components of the ATTIC system became available for use in a multi-user environment, they were added to the on-line system. In the first month of operation, the on-line system was accessed by more than 120 users.

ATTIC has been sucessfully demonstrated in U.S. EPA Regions 1, 3, 4 and 5 as well as to the respective environmental agencies in the states of California, Florida, New York and Washington. In particular, ATTIC personnel were invited by the Washington State Department of Ecology to participate in their hazardous waste management retreat on Sep. 1989. Response to the ATTIC System has been overwhelming positive. All demonstration participants have enthusiastically endorsed ATTIC and expressed the importance of a system which centralizes this type of information and disseminates background materials on request. The ATTIC System has also been referenced in the U.S. EPA Administrator's "A Management Review of the Superfund Program" (generally referred to as the 90-day study) as "...a strong step in the right direction and EPA should give priority to supporting and fully developing its capabilities." The Administrator's 90-day study also recommends that "...the Agency should establish an information clearinghouse within the Office of Research and Development containing data, reports and references from EPA, State and other evaluations of technology performance. The clearinghouse should include a computerized database that allows access through telephone inquiry on-line computer access, and printed material."[2]

The ATTIC is operated by TRI at their facility in Rockville, Maryland. It is housed in an IBM-PC compatible 386 machine in conjunction with a Novell network. The use of the Novell network has created an effective on-line system that allows up to eight user to access the system at one time through any modem-equipped PC using standard communication parameters. As previously mentioned, the system operator is still available to respond to information requests from the user community. However, users are able to access the ATTIC system and conduct searches of the various resources and download updates at their convenience.

FUTURE CONSIDERATIONS

The most important area of development for the ATTIC system in fiscal year 1990 should be the expansion and updating of the volume of information contained within the ATTIC Data Base. In addition to the information already obtained to date, new technical information should be acquired from a variety of new sources including:

- Defense Logistics Agency
- RCRA Corrective Actions
- Department of Energy
- State Treatability Data
- Industry Data
- Regional Data Bases

Highest priority should be placed on obtaining information and data that have a direct bearing on remediation of hazardous waste sites. Efforts should also be focused on expanding the information already present in the data base routinely updating this information to ensure that ATTIC is the most up-to-date source of treatment technology/remediation information available. These information sources include:

- SITE Program Data
- USATHAMA Installation and Restoration Activities
- Delisting Activities
- Records of Decision
- Region 3 Data Base on Treatment Technology
- Treatability Studies

Treatability studies will receive high priority during fiscal year 1990 in light of a recent memorandum from Henry L. Longest, Director of the Office of Emergency and Remedial Response, informing all Superfund Branch Chiefs that ATTIC is to serve as the source of all treatability study information in FY 1990.[3] The ATTIC Data Base should also be expanded to include the site location of each type of remedial activity that is being conducted.

Another area of consideration for fiscal year 1990 activities includes the development of an overall ranking system for the effectiveness of the various treatment technologies stored in the ATTIC Data Base.

When a request for information has been received by the ATTIC system operator and a search has been conducted, a list of reports that satisfy the specific key words used are generated. Abstracts for each of the reports are then provided to the user to determine which documents will be the most applicable to the user's information need. There is no distinction made between the reported effectiveness of each method presented in the reports. For specifics of that detail, the user must read the individual documents. The effectiveness of ATTIC could be greatly enhanced if the overall information obtained in a search request could be presented in a format that reflects the effectiveness of the reported treatment technology.

The proposed next step for ATTIC would be to rank each document contained within the system based on the effectiveness of the treatment technology employed. In addition, a summary report on the overall types of treatment technologies would be provided, ranked according to the effectiveness of the technology on the type of hazardous waste contaminant specified by the user. For example, a user contacts the ATTIC system with a request for information on treating heavy metal sludges that also contain high concentrations of organic solvents. Under the proposed system, ATTIC would generate a summary report on the treatment methods employed to treat heavy metal wastes and solvents, discussing the various options available to the user and presenting the most effective type of treatment available. ATTIC would also generate a list of documents that satisfy the specific key words, but would rank these by the effectiveness of method employed. The user would then be able to make an informed decision as to the type of treatment technology that could be employed at his site.

For this search process to be implemented, several key points must be understood. First, ATTIC is not acting as a consultant to the user and is not making any recommendations as to the type and kind of treatment technology that should be employed by the user at a site. The decision can only be made by the user. Second, ATTIC is basing rankings of the reports solely on the basis of the data presented in the individual documents. The purpose of the ranking format is to refine the available data and present the information to the user in such a way as to allow him to make an informed decision. Third, this approach

will allow the user to think of treatment technologies as a continuum, i.e., treatment trains, and not as individual isolated units.

CONCLUSION

Studies have indicated that the target audiences for the ATTIC System is larger than anticipated and includes more users within the private sector than expected. In particular, ATTIC should be designed to provide information on hazardous waste treatment primarily to the hazardous waste site remediation contractors as well as federal and state environmental agencies. Studies have also indicated that new and significant information needs to be incorporated into the ATTIC System to achieve a critical mass of technical data. The highest priority, therefore, should be placed on obtaining information and data that have a direct bearing on remediation of hazardous waste sites. Efforts should also be focused on expanding the information already present in the data base and routinely updating this information to ensure that ATTIC is the most up-to-date source of treatment technology/remediation information available.

For ATTIC to meet the recommendations of the Administrator's 90-day study to distribute high-quality technical information, an effective on-line computer system needs to be developed that will allow multiple users simultaneous access to the ATTIC system through any modem-equipped PC. Users should be able to access the ATTIC system, conduct searches and download updates as needed. A system operator should also be available to respond to information requests from those members of the user community who do not have communications capabilities or opt not to conduct their own searches. However, the PC-based network system currently in place should only be considered as an interim step before true on-line operation is achieved due to significant limitations associated with hardware, software, communications and general distribution. Surveys of the user community have indicated that the application of a true on-line system could greatly enhance the ability of the ATTIC system to rapidly disseminate technical data and information on alternative treatment technologies.

REFERENCES

1. Corbett, C.J., *Alternative Treatment Technology Information Center Beta Test Report*, U.S. EPA, Region III, Philadelphia, PA, June 1989.
2. Reilly, W.K., *A Management Review of the Superfund Program*, U.S. EPA, Washington, DC, 1989.
3. Longest II, H.L., *Memorandum to Superfund Branch Chiefs on Treatability Studies Contractor Work Assignments*, U.S. EPA, Washington, DC, July 12, 1989.

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Technological Innovation in Hazardous Waste Remediation

Walter W. Kovalick, Jr. and James B. Cummings
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The following is the first in a series of articles on various efforts to encourage and support innovation in hazardous waste treatment technologies for sites and affected groundwater. This article provides a brief discussion of the origins of the U.S. EPA's Office of Solid Waste and Emergency Response (OSWER) Technology Innovation Office (TIO), its mission, and the major initiatives underway or under contemplation. Subsequent articles will provide progress reports on these initiatives and other activities related to technology innovation by federal and state regulators, technology developers, responsible parties, the engineering community, and other interested parties.

There is an increasing awareness of the need for diversification in technologies to treat contaminated soil and groundwater. The ability of the U.S. Environmental Protection Agency (EPA) to achieve their preference for use of treatment and permanent remedies in the Superfund Amendments and Reauthorization Act (SARA) depends upon the availability of affordable, effective and publicly acceptable technologies.

The Technology Innovation Office (TIO) was established pursuant to one of the recommendations in EPA's 90-day Management Review of the Superfund Program. The recommendation arose from a recognition of the need to have an EPA advocate for innovation in the face of many countervailing forces and priorities. The scope of support for innovation encompasses Superfund, RCRA Corrective Action Sites, and remediation of leaking underground storage tanks.

TIO's mission is to stimulate the development and application of innovative treatment technologies, and to remove impediments that inhibit the use of such remedies. In particular, TIO efforts are focused on technologies which lack sufficient cost and performance data to allow routine consideration and selection.

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The Remediation Universe

For those who are unfamiliar with the nature and size of the hazardous site remediation universe, the numbers are daunting. More than 1200 sites are listed on the National Priorities List (NPL)—sites deemed sufficiently hazardous to warrant utilizing federal resources for clean-up. A larger number of abandoned sites are being investigated by state agencies. While these sites may generally be less contaminated than NPL sites, many will require some form of remedial action.

Less well-known, but certainly important, are contaminated sites potentially subject to corrective action under the Resource Conservation and Recovery Act (RCRA). More than 4700 facilities in the United States treat, store or dispose of hazardous waste. Although estimates vary, some 3700 RCRA facilities with approximately 64,000 solid waste management units may need corrective action.

Finally, it is estimated that 15 to 20 percent of the 5 to 7 million underground storage tanks are leaking across the United States.

The Department of Energy (DOE) and the Department of Defense (DOD) are responsible for remediation activities at their own facilities. According to the General Accounting Office, DOE alone has more than 3500 inactive units requiring environmental cleanup.

The large number of sites and the large volume of waste have resulted in staggering estimates for the overall cost of remediation. Innovative approaches have the promise of reducing costs in addition to improving performance and offering remedies more acceptable to the general public. However, sheer numbers alone do not tell the whole story. Complex subsurface conditions and complex mixtures of contaminants (e.g., organics and metals) also demand innovation if we are to be able to clean up some sites at all.

Innovation Initiatives

TIO serves as the U.S. EPA's Office of Solid Waste and Emergency Response (OSWER) interface with the Office of Research and Development's (ORD) Risk Reduction Engineering Laboratory (RREL) for the Superfund Innovative Technology Evaluation (SITE) program, a statutorily mandated program to assist in development and demonstration of promising remediation technologies. There are more than 75 technologies in the demonstration and emerging technol-

ogy programs and approximately 30 completed projects. A segment of the SITE program is also devoted to developing promising field monitoring methods.

To further facilitate development and application of new technologies, TIO is pursuing a number of additional projects discussed below.

- *A Market Assessment Project* is underway to profile the remediation market retrospectively and over the next several years. The objective is to provide developers and investors with information on the worst site problems so that development dollars can be channelled more productively. Site profiles may also help vendors market their technologies to site managers.
- *A Technology Incubators/Test and Evaluation (T&E) Facilities* project will evaluate the usefulness of facilities that can assist both in development and in evaluation of new technologies. Timely, credible treatability testing is an important component of remedy selection. Early testing is particularly important for innovative technologies which may lack a proven track record.
- *A Vendor Identification Database* project will compile screening level information on cost and performance from vendors and their clients. This information will provide a clearinghouse for companies, consulting engineers, and state and federal project managers.
- *The Bioremediation Field Initiative* is a joint effort between OSWER and ORD. The program is designed to more fully document performance of full-scale applications of bioremediation, provide technical assistance for treatability studies and field pilot studies, and enhance cross-regional information transfer on bioremediation projects.
- *Identifying and Removing Regulatory Impediments* is an ongoing function of TIO. The same regulatory framework which essentially establishes the market for remedial technologies unfortunately hampers the development and application of innovative technologies. The recently completed RCRA Implementation Study (RIS) contains a number of findings and recommendations regarding these regulatory impacts. Among the findings are that:
  1. Cost and timing to obtain a Research Development and Demonstration (RD&D) permit may impede innovation.
  2. Permit writers would benefit from additional guidance in writing permits for miscellaneous units covered by EPA's Subpart X regulations.
  3. Mobile treatment units intended for use at numerous sites would benefit from streamlined permitting. Such units may currently need to obtain a full hazardous waste treatment permit at each location. This potentially beneficial concept is currently caught up in the linkage between permitting and requirements for facility-wide corrective action.
  4. There is concern that stringent cleanup levels—Best Demonstrated Available Technology (BDAT)—being developed for soil and debris may delay innovation.

Several of these regulatory areas are the subject of continuing TIO efforts.

- *Federal Remediation Technologies Roundtable*—In cooperation with other Federal agencies that have both cleanup problems and technology demonstration interests, TIO is developing joint publication of summarizing reports, individual demonstration projects, and data bases which have information on innovative technologies. Future efforts will focus on joint or collaborative demonstration projects.
- *Information Dissemination*—TIO has compiled a bibliography of all significant EPA publications on innovative technologies. In addition, the office issues a periodic bulletin, "Tech Trends" dealing with experiences encountered in applying innovative technologies in the field, and is developing more comprehensive bibliographic descriptions of the status of innovative technologies.
- *Forum on Innovative Hazardous Waste Treatment Technologies*—TIO has sponsored two international conferences and will sponsor a third meeting in Dallas in June 1991. International and domestic vendors of innovative technologies will present papers and posters with an emphasis on actual field applications.
- *Encouraging State Initiative*—The numbers cited above regarding the size of the remediation universe indicate that the largest market for remediation technologies may be the states. In any event, state regulatory requirements and remediation programs will have a major impact on the pace and extent of innovation. For various reasons, states have been slow to adopt EPA-promulgated innovation support and relief mechanisms such as RD&D permits and the 1000kg treatability exclusion. TIO is working with a number of interested states to explore opportunities to establish a regulatory environment which not only tolerates, but actively encourages innovation.

In addition to these projects, TIO is exploring avenues to more fully engage the nation's consulting engineers, responsible parties, and professional societies in collaborative information sharing, education, and remediation technology demonstration.

* * * * *

The demand for hazardous waste treatment technologies is driven largely, if not totally, by regulatory requirements. Financial, technical, and regulatory factors, plus the availability of timely, accurate information on performance and cost result in a complex and dynamic market for innovation. Our understanding of the factors which contribute to uncertainties for both technology developers and users continues to evolve. TIO has been the beneficiary of valuable input from numerous sources in scoping the initiatives undertaken to date. Continued feedback from practitioners in both the public and private sector is essential to our ability to perform our mission.

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11.13 EXAMPLES OF CONSTITUENTS WITHIN WASTE GROUPS

EXAMPLES OF CONSTITUENTS WITHIN WASTE GROUPS

HALOGENATED VOLATILES
Bromodichloromethane
Bromoform
Bromomethane
Carbon tetrachloride
Chlorodibromomethane
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
Chloropropane
Dibromomethane
Cis,1,3-dichloropropene
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethene
1,2-Dichloroethene
1,2-Dichloropropane
Fluorotrichloromethane
Methylene chloride
1,1,2,2-tetrachloroethane
Tetrachloroethene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
1,2-Trans-dichloroethene
Trans-1,3-dichloropropene
1,1,2-trichloro-1,2,2-trifluoroethane
Trichloroethene
Vinyl chloride
Total chlorinated hydrocarbons
Hexachloroethane
Dichloromethane

HALOGENATED SEMIVOLATILES
2-chlorophenol
2,4-dichlorophenol
Hexachlorocyclopentadiene
p-chloro-m-cresol
Pentachlorophenol
Tetrachlorophenol
2,4,5-trichlorophenol
2,4,6-trichlorophenol
Bis-(2-chloroethoxy)methane
Bis(2-chloroethyl)ether
Bis(2-chloroisopropyl)ether
4-bromophenyl phenyl ether
4-chloroaniline
2-chloronapthalene
4-chlorophenyl phenylether

HALOGENATED SEMIVOLATILES (cont.)
Bis(2-chloroethoxy)phthalate
Bis(2-chloroethoxy)ether
1,2-bis(2-chloroethoxy)ethane

NONHALOGENATED VOLATILES
Acetone
Acrolein
Acrylonitrile
Benzene
2-butanone
Carbon disulfide
Cyclohexanone
Ethyl acetate
Ethyl ether
Ethyl benzene
2-hexanone
Isobutanol
Methanol
Methyl isobutyl ketone
4-methyl-2-pentanone
n-butyl alcohol
Styrene
Toluene
Trimethyl benzene
Vinyl acetate
Xylenes

NONHALOGENATED SEMIVOLATILES
Benzoic acid
Cresols
2,4-dimethylphenol
2,4-dinitrophenol
2-methylphenol
4-methylphenol
2-nitrophenol
4-nitrophenol
Phenol
Acenaphthene
Acenapthylene
Anthracene
Benzidine
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Benzo(ghi)perylene
Benzyl alcohol
Bis(2-ethylhexyl)phthalate

SOURCE: **Bioremediation of Hazardous Waste Sites Workshop** - Speaker Slide Copies and Supporting Information CERI-89-11

EXAMPLES OF CONSTITUENTS WITHIN WASTE GROUPS (cont)

HALOGENATED SEMIVOLATILES (cont.)
1,2-dichlorobenzene
1,3-dichlorobenzene
1,4-dichlorobenzene
3,3-dichlorobenzidine
Hexachlorobenzene
Hexachlorobutadiene
1,2,4-trichlorobenzene

PESTICIDES
Aldrin
Bhc-alpha
Bhc-beta
Bhc-delta
Bhc-gamma
Chlordane
4,4'-DDD
4,4'-DDE
4,4'-DDt
Dieldrin
Endosulfan I
Endosulfan II
Endosulfan sulfate
Endrin
Endrin aldehyde
Ethion
Aluminum
Heptachlor
Heptachlor epoxide
Malathion
Methylparathion
Parathion
Toxaphene

NONHALOGENATED SEMIVOLATILES (cont)
4,6-dinitro-2-methylphenol
2,4-dinitrotoluene
2,6-dinitrotoluene
Di-n-octyl phthalate
1,2-diphenylhydrazine
Fluoranthene
Fluorene
Indeno(1,2,3-cd)pyrene
Isophorone
2-methylnapthalene
Napthalene
2-nitroaniline
3-nitroaniline
4-nitroaniline
Nitrobenzene
n-nitrosodimethylamine
n-nitrosodi-n-propylamine
n-nitrosodiphenylamine
Phenanthrene
Pyrene
Pyridine
2-methynaphthalene
Bis phthalate
Phenyl napthalene
Ethyl parathion
Butyl benzyl phthalate
Chrysene
Dibenzo(a,h)anthracene
Dibenzofuran
Diethyl phthalate
Dimethyl phthalate
Di-n-butyl phthalate

VOLATILE METALS
Arsenic
Bismuth
Lead
Mercury
Tin
Selenium

OTHER CATEGORIES
Asbestos

SOURCE: **Bioremediation of Hazardous Waste Sites Workshop** - Speaker Slide Copies and Supporting Information CERI-89-11

EXAMPLES OF CONSTITUENTS WITHIN WASTE GROUPS (cont)

INORGANIC CORROSIVES
Hydrochloric acid
Nitric acid
Hydrofluoric acid
Sulfuric acid
Sodium hydroxide
Calcium hydroxide
Calcium carbonate
Potassium carbonate
PCBs
PCB (Arochlor)-1016
PCB (Arochlor)-1221
PCB (Arochlor)-1232
PCB (Arochlor)-1242
PCB (Arochlor)-1248
PCB (Arochlor)-1254
PCB (Arochlor)-1260
PCB NOS (not otherwise specified)

ORGANIC CORROSIVES
Acetic Acid
Acetyl chloride
Aniline
Aeromatic Sulfonic acids
Cresylic acid
Formic acid

NONMETALLIC TOXIC ELEMENTS
Fluorine
Bismuth

NONVOLATILE METALS
Aluminum
Antimony
Barium
Beryllium
Bismuth
Cadmium
Calcium
Chromium
Copper
Cobalt
Iron
Magnesium
Manganese
Nickel
Potassium
Selenium
Sodium
Vanadium
Zinc

RADIOACTIVES
Radioactive isotopes of
iodine, barium, uranium
Radium
Gamma radioactivity

ORGANIC CYANIDES
Organonitriles

OXIDIZERS
Chlorates
Chromates

REDUCERS
Sulfides
Phosphides
Hydrazine

INORGANIC CYANIDES
Cyanide
Metallic cyanides
(e.g., ferricyanide,
sodium cyanide)

SOURCE: **Bioremediation of Hazardous Waste Sites Workshop** - Speaker Slide Copies and Supporting Information CERI-89-11

Selecting Innovative Treatment Technologies: A Practitioner's Guide

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John Kingscott
Technology Innovation Office
U.S. Environmental Protection Agency
Washington, DC
Daniel Sullivan
ICF Incorporated
Fairfax, Virginia

ABSTRACT

The U.S. EPA provides a number of tools for decision-makers who must evaluate technologies to remediate contaminated soils and groundwater. This paper provides a "road map" to guide the reader through the variety of U.S. EPA resources available on innovative treatment technologies.

Some of the available resources include screening guides that assist site managers in matching waste types with appropriate technologies; a bibliography, entitled *Selected Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation*, listing relevant and current U.S. EPA reports on remedial technologies and how to obtain them; the ROD System (RODS) data base, which contains information on technologies selected for individual sites; Superfund Innovative Technology Evaluation (SITE) reports, which provide performance data on innovative technology demonstrations; and the Alternative Treatment Technology Information Clearinghouse (ATTIC), which is a computerized library of treatability studies.

Additional resources to be available in the near future include information on technologies used at removal and remedial sites and their implementation status; an expert system to help select appropriate biological treatment processes for remedial sites; and an enhancement of ATTIC with treatment technology case histories from the Department of Energy, the Department of Defense and the Department of the Interior

INTRODUCTION

SARA mandated the use of permanent remedies at Superfund sites. By definition, these remedies reduce the toxicity, mobility and volume of contamination. As noted in the *Management Review of the Superfund Program* (commonly referred to as the 90-Day Study), decision-makers are hesitant to select newly developed or innovative technologies for a variety of informational, institutional and economic reasons. The Technology Innovation Office (TIO) was created in 1990 within the U.S EPA's Office of Solid Waste and Emergency Response (OSWER) to identify and remove impediments to the broader application of innovative technologies to hazardous waste remediation. One of TIO's primary goals is to assist those who select hazardous waste cleanup technologies to identify and use new or innovative technologies when remediating contaminated soils and groundwater

A principal impediment to the use of innovative and alternative treatment technologies is the lack of up-to-date, objective data with which to initially evaluate a technology's performance and cost. Such data must be available early in the remedy screening process in order for an innovative technology to be fully considered during the feasibility study. In an effort to overcome this particular roadblock, the U.S. EPA has created a number of reference sources for use by U.S. EPA employees and others. These resources include computerized data bases, a reference library, numerous publications and the availability of dedicated groups of technical experts. Many of these resources are available to the general public with no user fees.

The purpose of this paper is to publicize these computerized, bibliographic and technical resources, to encourage their use and to present a "road map" or logical approach to their efficient application. The "Practitioner's Guide to Identifying Innovative Technologies"

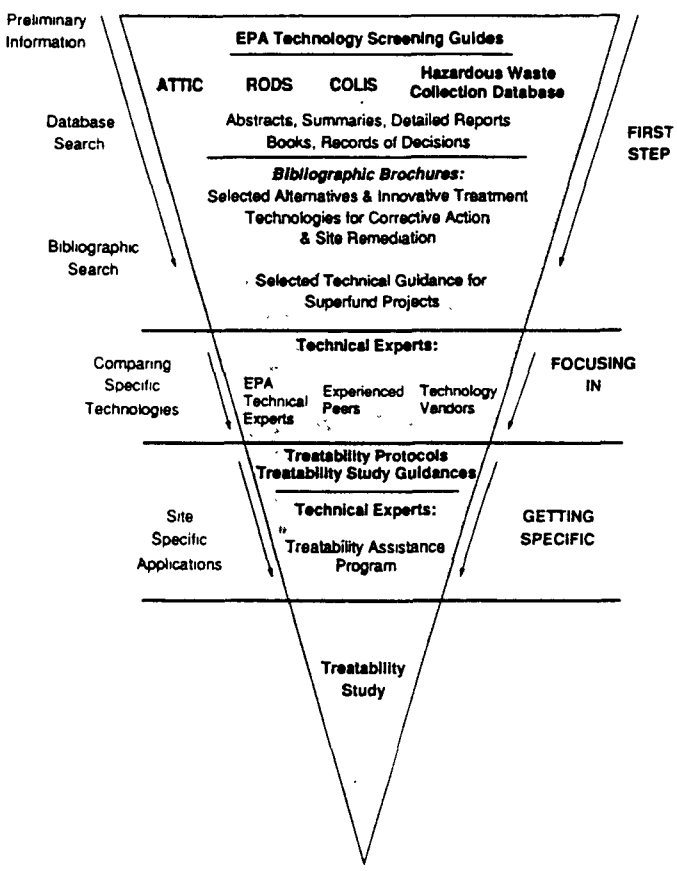


Figure 1
Practitioner's Guide to Identifying Innovative Technologies

Table 1
U.S. EPA Screening Guidelines for Treatment Technologies

- Technology Screening Guide for Treatment of CERCLA Soils and Sludges EPA/540/2-88/004
- Treatability Potential for EPA Listed Hazardous Wastes in Soil NTIS PB89-166581
- Treatability Potential for 56 EPA Listed Hazardous Wastes in Soil NTIS PB89-1744446
- Treatability of Hazardous Chemicals in Soils: Volatile and Semi-Volatile Organics NTIS DE89-016892
- Bioremediation of Contaminated Surface Soil NTIS PB90-164047
- Treatment Technology Fact Sheets.
  - Innovative Technology: Soil Washing
    OSWER Directive 9200 5-250-FS (Fact Sheet)
  - Innovative Technology: In-Situ Vitrification
    OSWER Directive 9200.5-251-FS (Fact Sheet)
  - Innovative Technology: BEST-TM Solvent Extraction Process
    OSWER Directive 9200.5-253-FS (Fact Sheet)
  - Innovative Technology: Glycolate Dehalogenation
    OSWER Directive 9200.5-254-FS (Fact Sheet)

(Fig. 1) provides an ordered approach to using the various data bases, publication sources and technical experts currently available from the U.S. EPA. This Guide can be used as a first step in identifying potential technologies that may be applicable to a specific contaminated site, as well as serving as a final check on available cost and performance data concerning various innovative remediation technologies that have already been identified through other means.

THE FIRST STEP

The streamlining of the Superfund remedial program in recent years requires the identification of remedial technologies during the early data gathering phases of the RI. During the early identification of technologies in the RI, the analyst needs to sift quickly through available information and identify what might be worth examining in more detail. A similar analysis may be conducted when time permits an engineering evaluation prior to a removal action.

The U S. EPA has prepared several screening documents which support an initial assessment of the possible application of technologies at sites. These documents (Table 1) provide an overview of potential technology use based on physical site characteristics and contaminant information. This information will help the analyst begin to identify potentially feasible technologies, to identify interfering waste and/or site characteristics and to identify process limitations. The screening guides should help focus attention on important technical issues and help identify key words or phrases for use during computer searches. Following this initial screening, data bases may be searched to identify useful references.

The U.S. EPA has created four data bases that are useful places to begin bibliographic technology research: ATTIC, the Hazardous Waste Collection Data Base, RODS and COLIS. The most recently developed of these four data bases, and likely the most pertinent to a technology search, is ATTIC—the Alternative Treatment Technology Information Clearinghouse ATTIC is the primary technology transfer mechanism for disseminating information concerning the Superfund Innovative Technology Evaluation (SITE) program and also contains abstracts and executive summaries from more than 1,500 technical documents and reports from states, industry, NATO, DOD, DOE other countries, Superfund RODs and various Superfund treatability studies. ATTIC can be accessed through modem-equipped personal computers or through a systems operator. The system is designed to search for key words with minimum effort, a site manager can receive short abstracts and summaries of possible applicable technologies. Should these summaries seem relevant, full copies of reports can be obtained through several sources including the U.S. EPA Library. Access to the on-line ATTIC system is available through the ATTIC system operator. Technical information requests also can be made by calling the system operator at (301) 816-9153.

The second data base of potential use during an early technology search is the Hazardous Waste Collection Database (HWCD), housed within the U.S. EPA Headquarters library. The HWCD, established in 1986 to support the information needs of the U.S. EPA's Superfund office, is a bibliographic data base containing abstracts of U.S. EPA and other government agency reports, trade books, policy and guidance directives, legislation and regulations concerning hazardous waste. Although the subject matter of HWCD is far more wide-ranging than the topic of innovative technologies, it is searchable by subject, reference title and key words using a menu. A data base thesaurus is available to aid users in designing efficient searches. One may contact Felice Sacks, the U.S. EPA Headquarters Head Hazardous Waste Superfund Librarian, at (202) 382-5934 for more information concerning the HWCD system.

A third useful data base is the Records Of Decision System (RODS) data base. The RODS data base contains the text of the signed Superfund Records of Decision. It facilitates comparing technologies used at sites with similar physical characteristics and waste conditions. The data base is menu-driven and provides rapid information searches. A search can be conducted on such fields as site name, remedy, key contaminants or the full text of the ROD. RODS is maintained on the U.S. EPA's IBM mainframe computer, which is located in Research Triangle Park, North Carolina. The RODS data base is available to the general public through the CERCLIS Hotline at (202) 252-0056 or the RODS staff at (202) 245-3770.

The fourth data base of interest is COLIS—the Computerized On-Line Information Systems. COLIS is part of the U.S. EPA's Risk Reduction Engineering Laboratory's (RREL) Technical Information Exchange. Three COLIS data bases are currently in operation:

- Case History File: This file contains information on site characteristics, respond methods, costs and cleanup problems related to spills, waste sites and underground storage tank management.
- Library Search System: This subsystem allows free form searching through catalog cards and full length abstracts of documents in the TIX library. Users may conduct their own literature searches using their own key words—they are not limited to a standard set of key words.
- SITE Application Analysis Report File: This subsystem allows free form searching of reports containing cost and performance data gathered from the U.S. EPA's SITE demonstration program. The reports are on-line in their entirety.

COLIS is accessible through the ATTIC system, or the system operator can be contacted at (201) 906-6871.

In addition to data bases services, the U.S. EPA also has prepared two brochures that will help identify U.S. EPA documents concerning the use of innovative and alternative remedial technologies. These brochures are titled *Selected Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation* (EPA/540/8-90/008, Oct. 1990) and *Selected Technical Guidance for Superfund Projects* (EPA/540/8-89/004, May 1989). Each of these two brochures lists more than 70 U.S. EPA documents relating to Superfund and remedial technologies. Both of these brochures are available free from the U.S. EPA's Center for Environmental Research Information (CERI) at (513) 569-7562.

FOCUSING IN

Each of these four computerized information sources allows users to gather a large number of potentially useful references in a relatively short period of time. The next step, therefore, is to pare down the reference list to those documents truly of interest. The technology screening guides listed in Table 1 should be helpful in this regard by assisting site managers to obtain a sense of the relevancy of individual references. The U.S. EPA and other sources also make available technology-specific publications and technical experts that can be consulted for detailed information regarding potentially useful remediation technologies.

Technology Specific Publications

By using general knowledge of site characteristics and an overview of potentially effective treatment technologies obtained from the screening guides mentioned above, the site manager has at this point identified references to a relatively small number of remediation technologies that are potentially useful. The next step is to locate and review documents concerning these technologies so that these few technologies can be compared with each other.

During the review of screening documents and technical literature, the analyst may become aware of important site characteristics which will determine the feasibility of some treatment processes. These factors may concern the physical or chemical character of the waste and suggest the need to promptly gather additional site data. Thus, an iterative process may develop where additional site data will be necessary to thoroughly assess technologies prior to conducting treatability studies.

Technical Experts

One of the challenges facing site managers is the need to assess the value of an innovative technology for the specific characteristics of a site. When reviewing the literature and considering technologies, the analyst should be aware of the developmental status of different technologies. By definition, innovative technologies are neither fully commercialized nor ready for "off-the-shelf" use. These technologies have limited performance and cost data and lack extensive field experience. The status of these processes may rapidly change, and new information is constantly being generated as demonstration projects and treatability studies are completed. Therefore, especially for new technologies, personal contact with technical experts, experienced peers and technology vendors is very important.

The U.S. EPA's Risk Reduction Engineering Laboratory (RREL) and Robert S. Kerr Environmental Research Laboratory (RSKERL) have experts on numerous treatment technologies that can quickly steer a site manager to pertinent and relevant information. The U.S. EPA sponsors several programs through each laboratory to provide this type of consultation. At the RREL, the U.S. EPA has established:

- The Engineering and Treatment Technical Support Center
- The Treatability Assistance Program
- The Superfund Technical Assistance Response Team

These three programs offer expertise in contaminant source control particularly in: above ground treatment units; materials handling; treatment of soils, sludge and sediments; and treatment of aqueous and organic liquids. They are intended to serve U.S. EPA site managers primarily, but are available to the public on a limited basis. For further information regarding these programs, one can contact Ben Blaney at (513) 569-7406.

Similarly, at the RSKERL, the U.S. EPA has established a Technical Support Center to deal with in situ biorestoration of soils and technologies affecting groundwater. For further information concerning these programs, one can contact Richard Scoff at (405) 332-8800.

The U.S. EPA has published reference guides to help identify ongoing programs and individuals who are working in specific technical areas. These guides are listed in Table 2. In addition, the SITE program has ben actively working with developers of innovative technologies for the last 4 yr. The program has a technology transfer effort intended to provide support to those in the hazardous waste site remediation community. The annual SITE Program brochure lists the U.S. EPA Office of Research and Development project managers and their associated technologies of interest. For additional information, one can contact John Martin at (513) 569-7758.

The five Hazardous Substance Research Centers are another source of technical expertise funded by the U.S. EPA (Table 3). These university-based centers, each of which has established special relations with a pair of U.S. EPA Regions, focus on problems common within their geographic regions, with emphasis on a specific area of research. These areas of specialization include groundwater remediation, incineration, bioremediation, recovery of metals and other physical and chemical treatment of surface and subsurface contaminants. The centers perform long- and short-term research on all aspects of hazardous substance generation, management, treatment and disposal. The centers are committed to technology transfer, as well. The activities of these centers are described more fully in *Hazardous Substance Research Center: Annual Report FY 1989* (January 1990). For a copy of this report or more information regarding these research centers, one can contact Karen Morehouse at (202) 382-5750.

Table 2
EPA Reference Guides to Technical Experts

- Groundwater Research· Technical Assistance Directory EPA/600/9-89/048
- Environmental Protection Agency, Office of Research and Development Technical Assistance Directory CERI-88-84
- ORD Topical Directory EPA/600/9-86/006
- Technical Support Services for Superfund Site Remediation EPA/540/8-90/011 October 1990

Table 3
Hazardous Substance Research Centers and Directors

- Dr. Richard Magee, Director
  Hazardous Substance Management Research Center
  New Jersey Institute of Technology
  Newark, New Jersey 07102
  201/596-3233

  Region-Pair 1/2: CT, MA, ME, NH, NJ, NY, PR, RI, VI, VT

- Dr. Walter J. Weber, Jr
  Dept of Civil Engineering
  2340 C.G. Brown Building
  University of Michigan
  Ann Arbor, Michigan 48109-2125
  313/763-2274

  Region-Pair 3/5· DC, DE, IL, IN, MD, MI, MN, OH, PA, VA, WI, WV

- Dr. Michael R. Overcash
  Dept. of Chemical Engineering
  North Carolina State University
  Raleigh, North Carolina 27695-7001

  Region-Pair 4/6: AL, AR, FL, GA, KY, LA, MS, NM, NC, OK, SC, TN, TX

- Dr. Larry E. Erickson
  Dept of Chemical Engineering
  Durland Hall
  Kansas State University
  Manhattan, Kansas 66506
  913/532-5584

  Region-Pair 7/8: CO, IA, KS, MO, MT, ND, NE, SD, UT, WY

- Dr. Perry L. McCarty
  Center Director
  Dept. of Civil Engineering
  Stanford University
  Stanford, California 94308
  415/723-4131

  Region-Pair 9/10· AK, American Samoa, AZ, CA, Guam, HI, ID, Northern Mariana Islands, NV, OR, WA

GETTING SPECIFIC

After identifying innovative treatment technologies with a potential for success at a site, treatability studies will likely be necessary to ascertain the effectiveness of technologies for the given site conditions and waste characteristics. The U.S. EPA provides several services to help make this task easier. The most basic are the publications entitled *Treatability Studies Under CERCLA: An Overview* (OSWER Directive 9380 3-02FS) and *Guide for Conducting Treatability Studies Under CERCLA, Interrim Final* (EPA/540/2-89/058) These publications

are available through the Superfund Docket and CERI, respectively (Table 2).

Through the Risk Reduction Engineering Laboratory, the U.S. EPA sponsors the previously mentioned Treatability Assistance Program. This program offers a list of contractors available to perform treatability studies, a comprehensive data base of all aqueous treatability studies and brief bulletins describing the applicability of various technologies. The Treatability Assistance Program is also in the process of developing generic technology specific treatability study protocols.

CONCLUSION

The U.S. EPA is assembling a comprehensive set of materials to make hazardous waste site managers aware of the resources available concerning innovative remedial technologies and to help steer them toward use of innovative remedial technologies. A logical approach to use of these materials is:

- To reference screening guides and assess overall technology potential
- To conduct a series of comprehensive data base searches
- To consult available bibliographies
- To screen the computer-generated reference lists, abstracts and bibliographies and obtain those publications and documents identified as having direct relevance to the project
- To contact recognized experts in the field of hazardous waste site remediation and engineering
- To conduct treatability studies using site-specific conditions and wastes

The Technology Innovation Office continues it's efforts to make more technology-specific information available to the hazardous waste site remediation community. Future plans call for the development of an innovative technology vendor data base, the expansion of the ATTIC system to include other data bases (thereby offering one-stop shopping), the development of a computerized expert system to assist in the selection of appropriate types of biological treatment and an expansion and improvement of SITE program information availability.

A critical factor in the success of the innovative technology information systems is the timeliness of the information it contains. "Innovation" by definition means "new," and all data in the U.S. EPA systems need to be continually updated or the system becomes simply one more impediment to using innovative technologies. Data and information concerning innovative technologies must be made widely available before these technologies can be fully evaluated and their potentials realized.

The U.S. EPA's Technical Innovation Office would also like to integrate information from outside sources, such as remediation contractors, other federal agencies and private industry, into its various technology transfer mechanisms. We have begun an outreach program designed to help collect and collate cost and performance data for innovative remediation technologies wherever it is available.

DISCLAIMER

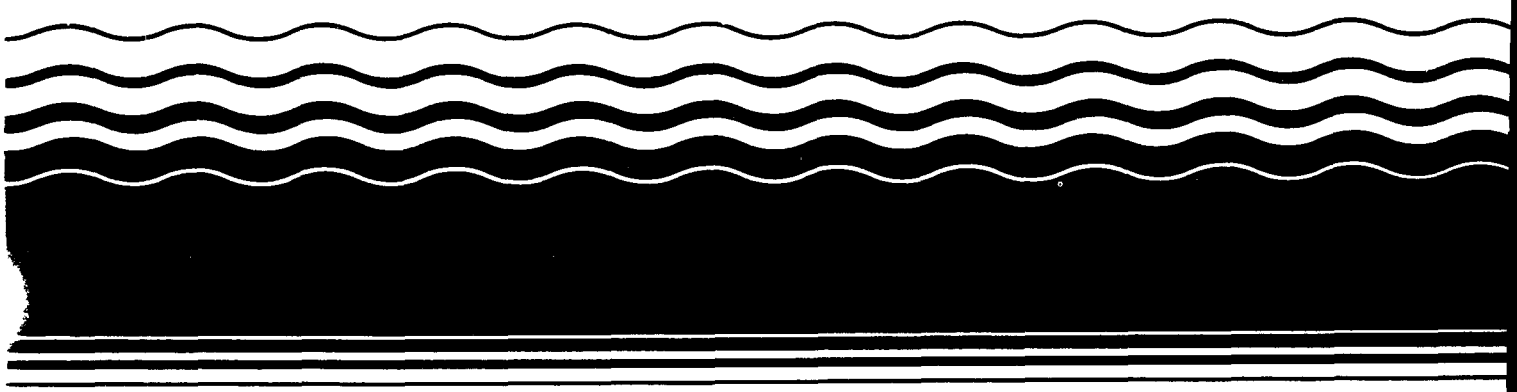
The opinions expressed in this article are those of the authors, and do not necessarily reflect the policy position of the U.S. EPA.

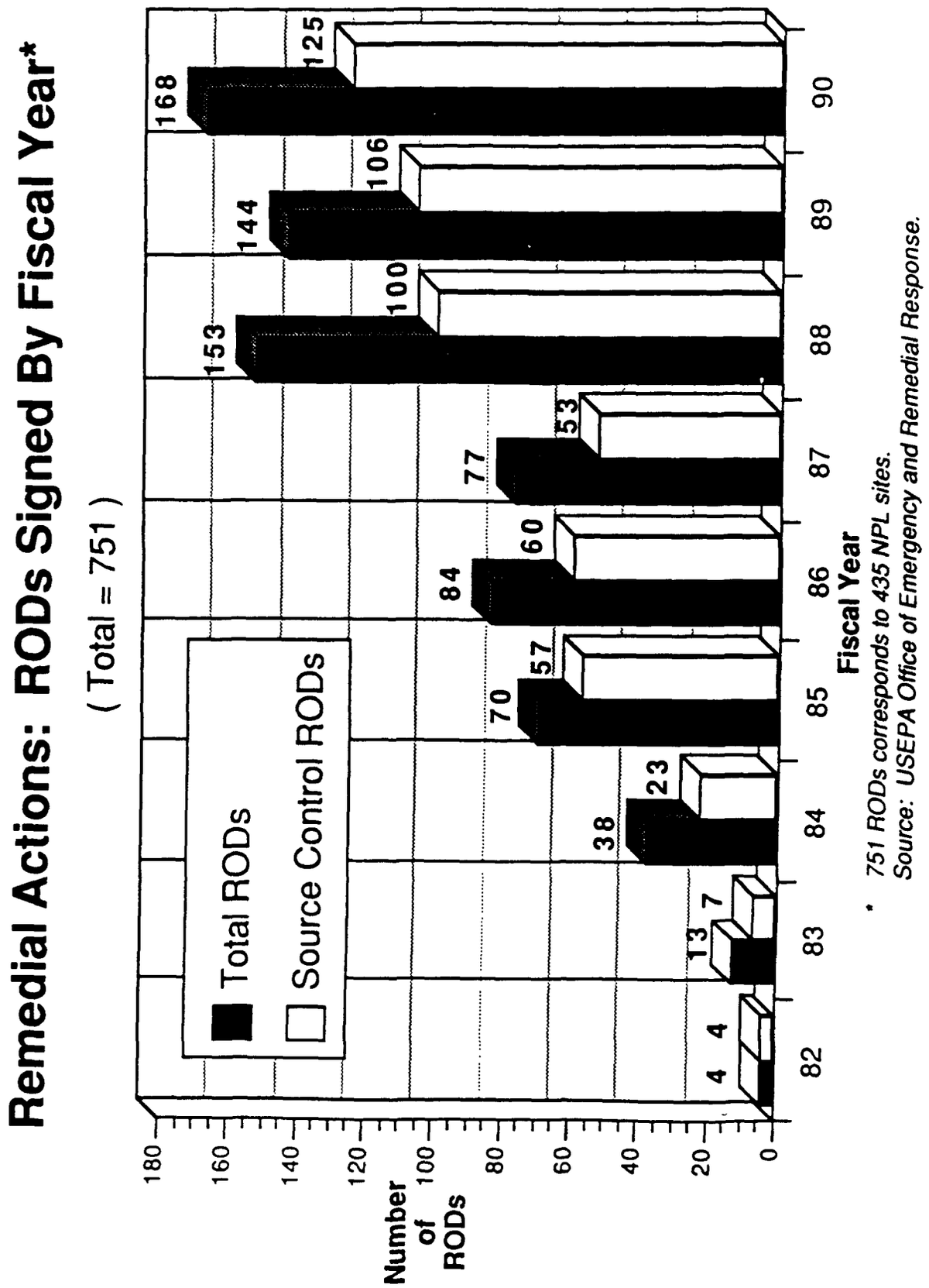
United States Environmental Protection Agency | Office of Research and Development Washington, DC 20460 | EPA/540/2-91/010 June 1991

Superfund

EPA

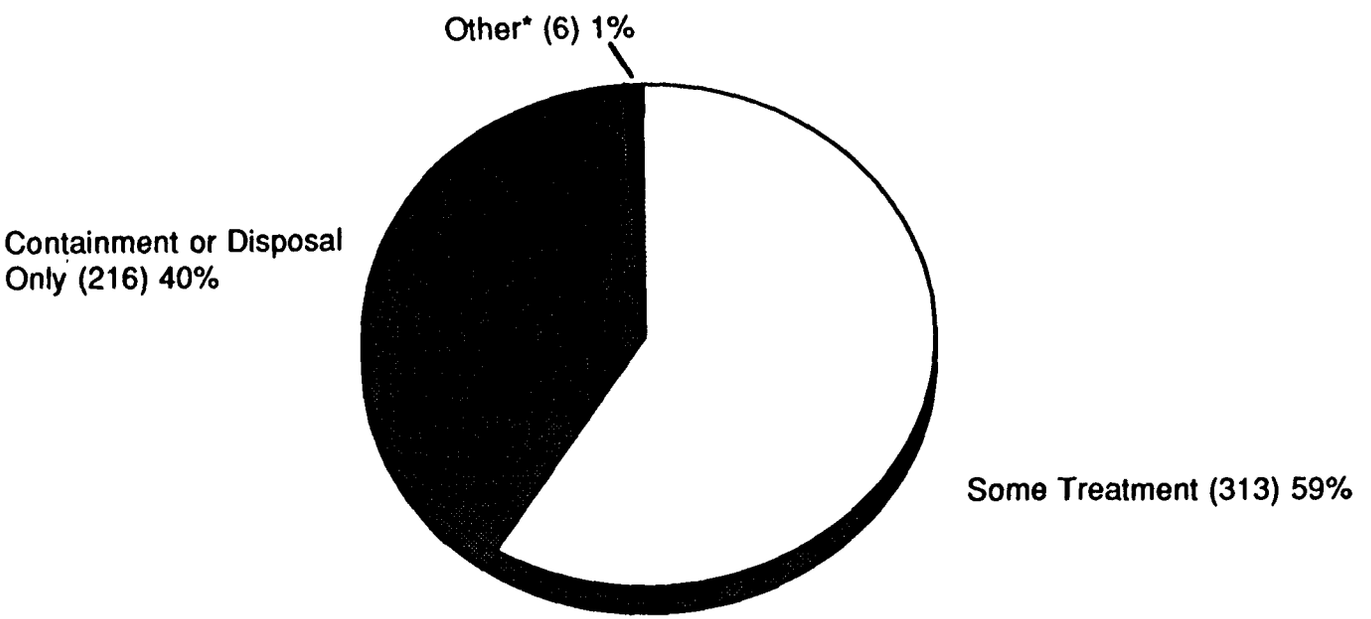
Survey of Materials-Handling Technologies Used at Hazardous Waste Sites





* *751 RODs corresponds to 435 NPL sites.*
Source: USEPA Office of Emergency and Remedial Response.

Remedial Actions: Overview of All Source Control RODs Through FY 90

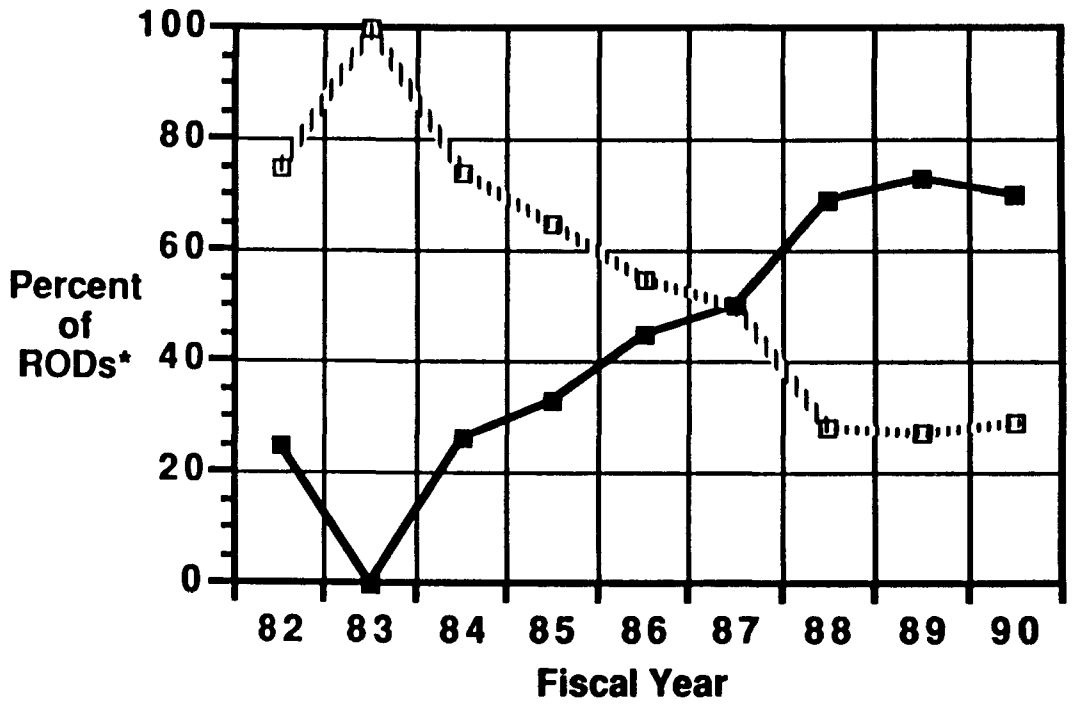


* *Includes institutional controls, monitoring, and relocation.*

( ) *Number of Records of Decision (RODs) for source control.*

Source: USEPA Office of Emergency and Remedial Response.

Remedial Actions:
Treatment Versus Disposal RODs for Source Control



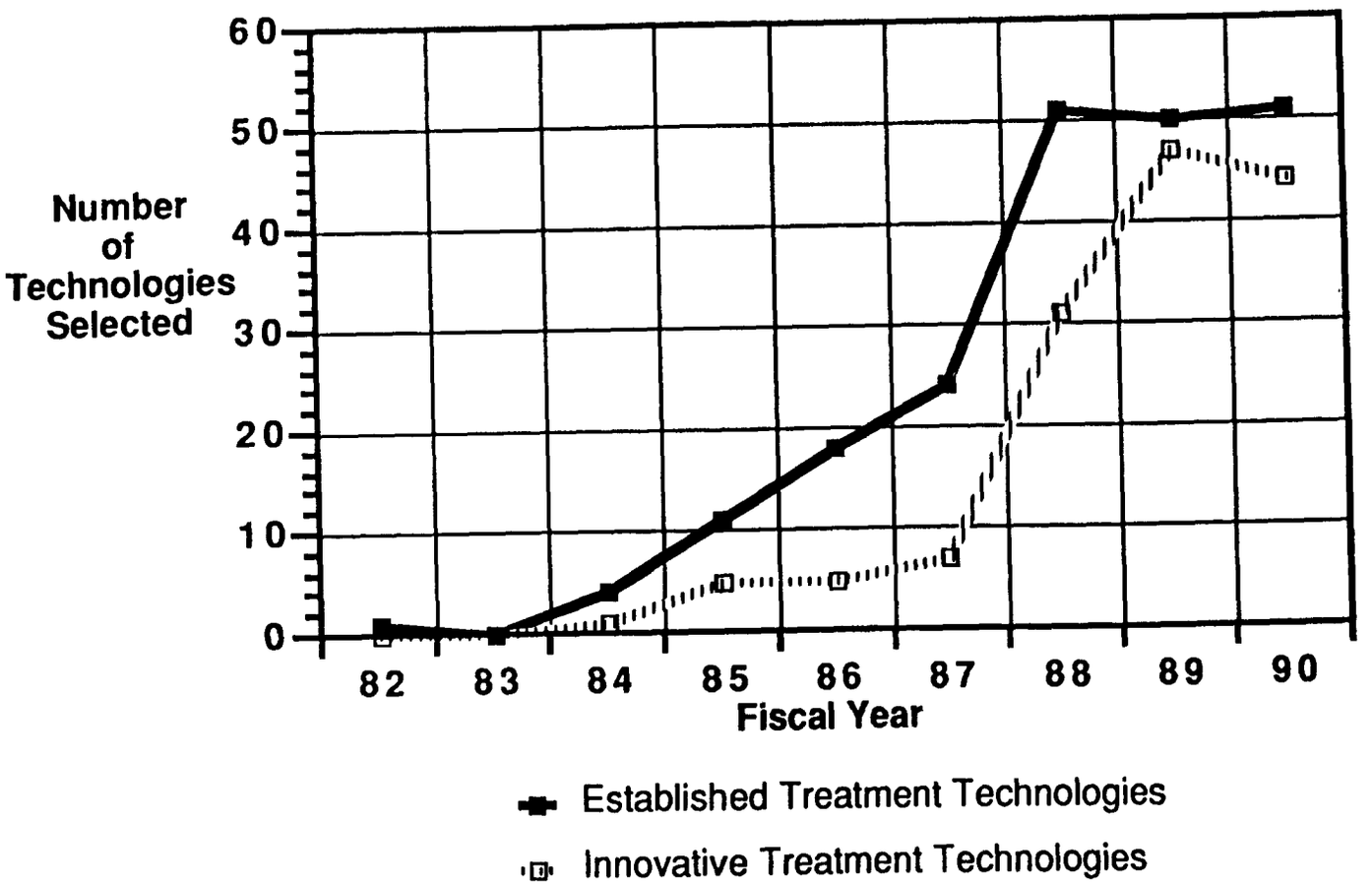
Some Treatment

Containment, Containment & Disposal, or Off-Site Disposal

* **RODs – Records of Decision**

Source: USEPA Office of Emergency and Remedial Response.

Remedial Actions: Number of Established Versus Innovative Treatment Technologies



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12.0 BIBLIOGRAPHY

Bibliography of Federal Reports and Publications Describing Alternative and Innovative Treatment Technologies For Corrective Action and Site Remediation

Prepared by the

Member Agencies of the Federal Remediation Technologies Roundtable

NOTICE

The information in this document has been funded wholly in part by the United States Environmental Protection Agency under Contract 68-CO-0083 and 68-01-7481 to ICF, Inc. It has been subject to administrative review by all agencies participating in the Federal Remediation Technologies Roundtable, and has been approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Bibliography of Federal Reports and Publications Describing Alternative and Innovative Treatment Technologies For Corrective Action and Site Remediation

Prepared by the Member Agencies of the
Federal Remediation Technologies Roundtable:

U.S. Environmental Protection Agency
Department of Defense
- U.S. Army
- U.S. Army Corps of Engineers
- U.S. Navy
- U.S. Air Force

Department of Energy
Department of Interior
- Bureau of Reclamation

Summer 1991

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PREFACE

The Federal Remediation Technologies Roundtable (Roundtable) developed this bibliography to publicize the accessibility of Federal documents pertaining to innovative and alternative technologies to treat hazardous wastes. The bibliography contains references for documents and reports from the U.S. Environmental Protection Agency (EPA), the U.S. Army, the U.S. Army Corps of Engineers, the U.S. Navy, the U.S. Air Force, the Department of Energy (DOE), and the Department of Interior (DOI), Bureau of Reclamation. The Roundtable obtained this reference information from a variety of resources:

- Publication lists from the Robert S. Kerr Environmental Research Laboratory (EPA), the Oak Ridge National Laboratory, and the Pacific Northwest National Laboratory (DOE);
- Federal Agency report, project and publication lists from EPA, the Naval Civil Engineering Laboratory, the U.S. Army Toxic and Hazardous Materials Agency, the Air Force Engineering and Sciences Center, and the U.S. Department of Defense (DoD); and
- National Technical Information Service (NTIS), DOE, Enviroline, and other database searches.

This bibliography addresses technologies which provide for the treatment of hazardous wastes; therefore, it does not contain information or references for containment or other non-treatment strategies, such as landfilling and capping. Although there are some references for more conventional treatment technologies, such as incineration and solidification, the main focus of this bibliography is on innovative technologies for which detailed cost and performance data are not available.

In addition to improving access to information on innovative technologies, the Roundtable hopes this bibliography will assist in the coordination of ongoing research initiatives, and increase the development and implementation of these innovative technologies for corrective action and site remediation. This bibliography is intended to serve as a starting point in your pursuit of information on innovative alternative hazardous waste treatment technologies and should not be considered the sole source for this type of information. At the end of this document (see page 21), you will find instructions for ordering publications you may be interested in.

This bibliography is scheduled to undergo periodic revisions. Therefore, if your Agency has produced any publications on innovative remediation technologies that should be included in future versions of this bibliography, or if you have any suggestions for improving this document, please complete the suggestion form on page 23, or contact the EPA Technology Innovation Office:

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A. INTERNATIONAL SURVEYS AND CONFERENCES

EPA

- *Assessment of International Technologies for Superfund Applications: Technology Review and Trip Report Results.*
  EPA/540/2-88/003

- *Assessment of International Technologies for Superfund Applications: Technology Identification and Selection.*
  EPA/600/2-89/017

- *Forum on Innovative Hazardous Waste Treatment Technologies, Domestic and International,* Atlanta, GA.
  EPA/540/2-89/056 (Technical Papers)

- *Second Forum on Innovative Hazardous Waste Treatment Technologies, Domestic and International.*
  EPA/540/2-90/009 (Abstracts)
  EPA/540/2-90/010 (Technical Papers)

- *NATO/CCMS Project – International Evaluation of In Situ Biorestoration of Contaminated Soil and Groundwater.*
  EPA/540/2-90/012

- *Second International Conference on New Frontiers for Hazardous Waste Management: Proceedings of a Conference Held in Pittsburgh, PA, Sept. 27-30, 1987.*
  EPA/600/9-87/018F

- *Third International Conference on New Frontiers for Hazardous Waste Management: Proceedings of a Conference Held in Pittsburgh, PA, Sept. 10-13, 1989.*
  EPA/600/9-89/072

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- *Bioremediation of Mercury-Contaminated Sites: Foreign Trip Report, Sept. 9-17, 1989.* Turner, R.R. Oak Ridge National Laboratory, DOE, TN. Sept. 1989.
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B. TECHNOLOGY SURVEY REPORTS

EPA

- *Approaches for Remediation of Uncontrolled Wood Preserving Sites.*
  EPA/625/7-90/011

- *Assessing Detoxification and Degradation of Wood Preserving and Petroleum Wastes in Contaminated Soil.* April, W., R. Sims, and J. Sims. Waste Management & Research. 8(1): 45-65. Feb. 90.
  EPA/600/J-90/009; NTIS: PB 90-243275

- *A Compendium of Technologies Used in the Treatment of Hazardous Waste*
  EPA/625/8-87/014

- *Guidance on Remedial Action for Superfund Sites with PCB Contamination.*
  EPA/540/G-90/007

- *Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites.* Office of Environmental Engineering and Technology, U.S. EPA, Washington, D.C. Mar. 1989.
  EPA/540/2-89/052; NTIS: PB 89-190821/XAB

- *Handbook on In Situ Treatment of Hazardous Waste-Contaminated Soils.*
  EPA/540/2-90/002

- *In Situ Restoration Techniques for Aquifers Contaminated with Hazardous Wastes.* Lee, M.D., J.T. Wilson, and C.H. Ward. Journal of Hazardous Materials. Elsevier Science Publishers B.V. Amsterdam, The Netherlands. 14: 71-82. 1987.
  EPA/600/J-87/032; NTIS: PB 87-198396

- *Innovative Operational Treatment Technologies for Applications to Superfund Sites.*
  EPA/540/2-90/006
  EPA/540/2-90/004 (Nine Case Studies)

- *Innovative Processes for Reclamation of Contaminated Subsurface Environments.* Canter, L.W., L.E. Streebin, M.C. Arquiaga, F.E. Carranza, and B.H. Wilson.
  EPA/600/2-90/017 (Project Summary); NTIS: PB 90-199514

- *Innovative Treatment Technologies: Semi-Annual Status Report.* Jan. 1991.
  EPA/540/2-91/001

- *Mobile Treatment Technologies for Superfund Wastes.*
  EPA/540/2-86/003f

- *Report on Decontamination of PCB-Bearing Sediments.* Wilson, D.L. Hazardous Waste Engineering Research Laboratory, U.S. EPA, Cincinnati, OH. Oct. 1987.
  EPA/600/2-87/093

- *Review of In-Place Treatment Techniques for Contaminated Surface Soils. Volume I. Technical Evaluation.*
  EPA/540/2-84/003a

- PCB (Polychlorinated Biphenyl) Sediment Decontamination, Technical/Economic Assessment of Selected Alternative Treatments: *Final Report, Jun. 1985-Feb. 1986.* Carpenter, B.H. Hazardous Waste Engineering Research Laboratory, U.S. EPA, Cincinnati, OH. Dec. 1986.
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- *Seminar Publication – Corrective Actions: Technologies and Applications.*
  EPA/625/4-89/020

- *Summary of Treatment Technology Effectiveness for Contaminated Soil: Final Report.*
  EPA/540/2-89/053

- *Superfund Innovative Technology Evaluation (SITE) Program -- Brochure.*
  EPA/540/8-89/010

- *Superfund Innovative Technology Evaluation Program -- SITE Program Fact Sheet*
  OSWER Directive 9330.1-03FS

- *Superfund Innovative Technology Evaluation Program: Technology Profiles.*
  EPA/540/5-90/006

- *Superfund Treatability Clearinghouse Abstracts.*
  EPA/540/2-89/001

- *Technical Resource Document: Treatment Technologies for Halogenated Organic Containing Wastes.* Volume I.
  EPA/600/2-87/098

- *Technologies for Delivery or Recovery for the Remediation of Hazardous Waste Sites.*
  EPA/600/S2-89/066 (Project Summary)

- *Technologies for In Situ Treatment of Hazardous Wastes.* Sanning, D.E. and R.F. Lewis. Hazardous Waste Engineering Research Laboratory, U.S. EPA, Cincinnati, OH. Jan. 1987.
  EPA/600/D-87/014; NTIS: PB 87-146007/XAB

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- *Treatment Potential for 56 EPA Listed Hazardous Chemicals in Soil.* Sims, R.C., W.J. Doucette, J.E. McLean, W.J. Greeney, and R.R. Dupont. Feb. 1988.
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- *Treatment Technology Background Document.* Berlow, J.R. and J. Vorbach. Office of Solid Waste, U.S. EPA, Washington DC. Jun. 1989.
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U.S. Army

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C. TREATABILITY STUDIES (General)

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- *Results of Treatment Evaluations of Contaminated Soils.* Esposito, P., J. Hessling, B.B. Locke, M. Taylor, and M. Szabo. Hazardous Waste Engineering Research Laboratory, U.S. EPA, Cincinnati, OH. Aug. 1988.
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- *Treatability Potential For EPA Listed Hazardous Wastes in Soil.* Loehr, R.C.
  EPA/600/2-89/011; NTIS: PB 89-166581 (Available from EPA, Ada, OK)

- *Treatability Potential for 56 EPA Listed Hazardous Chemicals in Soil.*
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D. THERMAL PROCESSES

EPA

- *Applications Analysis Report (SITE Program) -- American Combustion Pyretron Destruction System.*
  EPA/540/A5-89/008

- *Applications Analysis Report (SITE Program) -- Shirco Infrared Incineration System.*
  EPA/540/A5-89/007 (Also available in videocassette from EPA, Edison, NJ)

- *Engineering Bulletin -- Mobile/Transportable Incineration Treatment.*
  EPA/540/2-90/014

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- *Economic Evaluation of Low Temperature Thermal Stripping of Volatile Organic Compounds from Soil: Technical Report.* Marks, P.J. and J.W. Noland. U.S. Army Toxic and Hazardous Materials Agency Aug. 1986.
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E. SOLIDIFICATION/STABILIZATION

EPA

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- *Evaluation of Solidification/Stabilization as Best Demonstrated Available Technology for Contaminated Soils.*
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- *Feasibility of In Situ Solidification/Stabilization of Landfilled Hazardous Wastes.*
  EPA/600/2-83/088

- *Handbook for Stabilization/Solidification of Hazardous Waste.*
  EPA/540/2-86/001

- *Interference Mechanisms in Waste Stabilization/Solidification Processes.* Jones, L.W. Risk Reduction Engineering Laboratory, U.S. EPA, Cincinnati, OH. Jan. 1990.
  EPA/600/2-89/067

- *In Situ Stabilization/Solidification of PCB-Contaminated Soil.*
  EPA/600/D-89/119

- *The Morphology and Microchemistry of Solidified/Stabilized Hazardous Waste Systems.*
  NTIS: PB 90-134156/AS

- *Perspectives on Solidification/Stabilization Technology for Treating Hazardous Waste.*
  EPA/600/D-87/027

- *Physical Properties and Leach Testing of Solidified/Stabilized Industrial Wastes.*
  EPA/600/2-82/099

- *Review of Solidification/Stabilization Technology.*
  EPA/600/J-87/019

- *SITE Demonstration of the CHEMFIX Solidification/Stabilization Process at the Portable Equipment Salvage Company Site*
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- *Status of Solidification/Stabilization in the United States and Factors Affecting Its Use.*
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- *Survey of Solidification/Stabilization Technology for Hazardous Industrial Wastes.*
  EPA/600/2-79/056

- *Systems to Accelerate In Situ Stabilization of Waste Deposits.*
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  EPA/600/J-89/425

- *Adaptation to and Biodegradation of Xenobiotic Compounds by Microbial Communities from a Pristine Aquifer.* Aelion, C.M., C.M. Swindoll, and F.K. Pfaender. Appl. Environ. Microbiol. 53(9): 2212-2217. Sept. 1987.
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- *Innovative Technology Slurry-Phase Biodegradation*
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