REMEDIATION TECHNOLOGIES SCREENING MATRIX AND REFERENCE GUIDE

SECOND EDITION

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Prepared by the

DOD Environmental Technology
Transfer Committee

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FOREWORD

The Environmental Technology Transfer Committee (ETTC) was established in 1981 to facilitate the exchange of programmatic and technical information involving remediation activities among DOD services. The ETTC charter later expanded to include DOE and EPA membership as well as environmental activities other than remediation. The Federal Remediation Technology Roundtable (FRTR) was established in 1991 as an interagency committee to exchange information and provide a forum for joint action regarding the development and demonstration of innovative technologies for hazardous waste remediation.

One of the distinctive attributes of environmental technology is that the state-of-the-art continually changes. Federal agencies have periodically updated and published information on remediation technologies in an effort to keep pace with these changes. However, government remedial project managers (RPMs) must often sort through large volumes of related and overlapping information to evaluate alternative technologies. To assist the RPM in this process and to enhance technology transfer among federal agencies, we developed this document to combine the unique features of several agency publications into a single document. It allows the RPM to pursue questions based on contamination problems as well as specific technology issues depending on their need.

The selection and use of innovative technologies to clean up hazardous waste sites is increasing rapidly, and new technologies are continuing to emerge. Member agencies plan to issue periodic updates of this document to help the RPM keep pace with the ever-changing range of technology options available.

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13. ABSTRACT Under subcontract to the U.S. Army Environmental Center, Roy F. Weston, Inc. (WESTON®) has prepared the *Remediation Technologies Screening Matrix and Reference Guide*, Second Edition. The purpose of this document is to provide enough information to allow the reader to use the guide, in combination with other references, to efficiently proceed from identifying a contaminated site toward communicating and recommending suitable site remediation technologies to environmental regulators. The approach used to prepare this document was to review and compile the unique features of several U.S. Government documents into one compendium document. Information on widely used and presumptive remedies is provided in order to minimize the amount of remediation resources used in obtaining site charac-terization data and/or evaluating every possible remedial alternative. Presumptive remedies are preferred technologies for common categories of sites established by the U.S. Environmental Protection Agency (EPA), based on historical patterns of remedy selection and EPA's scientific and engineering evaluation of performance data on technology implementation. Commercially available innovative technologies are

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LIST OF ACRONYMS

AFB	U.S. Air Force Base
AIChE	American Institute of Chemical Engineers
ALARA	As Low As Reasonably Achievable
APA	Air Pathway Analysis
APEG	Alkaline Polyethylene Glycolate
APG	Aberdeen Proving Ground, Maryland
AST	Aboveground Storage Tank
AWMA	Air and Waste Management Association
AWWA	American Water Works Association
BOD	Biochemical Oxygen Demand
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
CAA	Clean Air Act
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (also known as Superfund)
CERL	U.S. Army Construction Engineering Research Laboratory
COD	Chemical Oxygen Demand
CROW	Contained Recovery of Oily Waste
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
CWA	Clean Water Act
DNAPL	Dense Non-Aqueous Phase Liquid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
DRE	Destruction and Removal Efficiency
EPA	U.S. Environmental Protection Agency
ERD	Environmental Restoration Division
ERL	Environmental Research Laboratory
ETTC	DOD Environmental Technology Transfer Committee
FRTR	Federal Remediation Technologies Roundtable
FS	Feasibility Study
GAC	Granular-Activated Carbon
HEC	High Energy Corona
HLRW	High Level Radioactive Waste
HMCRI	Hazardous Materials Control Research Institute
HTTD	High Temperature Thermal Desorption
HWAC	Hazardous Waste Action Council

IR	Installation Restoration
IRHWCT	Installation Restoration and Hazardous Waste Control Technologies
ISEE	In Situ Steam-Enhanced Extraction
ISV	In Situ Vitrification
KPEG	Potassium Polyethylene Glycolate
LDR	Land Disposal Restriction
LLRW	Low Level Radioactive Waste
LNAPL	Light Non-Aqueous Phase Liquid
LTTD	Low Temperature Thermal Description
MCL	Maximum Contaminant Level
MRD	U.S. Army Missouri River Division
NAPL	Non-Aqueous Phase Liquid
NAS	Naval Air Station
NCA	Noise Control Act
NCEL	Naval Civil Engineering Laboratory, now NFESC
NCP	National Contingency Plan
NEESA	Navy Energy and Environmental Support Activity, now NFESC
NEPA	National Environmental Policy Act of 1969
NFESC	Naval Facilities Engineering Service Center
NPDES	National Pollutant Discharge Elimination System
NPL	National Priority List
NRC	U.S. Nuclear Regulatory Commission
NWS	Naval Weapons Station
O&M	Operations and Maintenance
OB/OD	Open Burn/Open Detonation
ODW	EPA Office of Drinking Water
OERR	EPA Office of Emergency and Remedial Response
ORD	EPA Office of Research and Development
OSHA	Occupational Safety and Health Administration
OSW	EPA Office of Solid Waste
OSWER	EPA Office of Solid Waste and Emergency Response
PACT	Powdered-Activated Carbon Technology
PAH	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PCP	Pentachlorophenol
PEP	Propellants, Explosives, and Pyrotechnics
POC	Point of Contact
POL	Petroleum, Oils, and Lubricants
R&D	Research and Development
RBC	Rotating Biological Contactor
RCRA	Resource Conservation and Recovery Act
RCRIS	Resource Conservation and Recovery Information System
RI/FS	Remedial Investigation/Feasibility Study

ROD	Record of Decision
RPM	Remedial Project Manager
RREL	EPA Risk Reduction Engineering Laboratory
RSKERL	EPA's Robert S. Kerr Environmental Research Laboratory
scfm	Standard Cubic Feet per Minute
SERP	Steam-Enhanced Recovery Process
SITE	Superfund Innovative Technology Evaluation
SIVE	Steam Injection and Vacuum Extraction
SNF	Spent Nuclear Fuel
SVE	Soil Vapor Extraction
SVOC	Semivolatile Organic Compound
TCE	Trichlorethylene
TCLP	EPA Toxicity Characteristic Leaching Procedure
TI	Technical Impracticability
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TRU	Transuranic Waste
TSCA	Toxic Substance Control Act
USACE	U.S. Army Corps of Engineers
USAEC	U.S. Army Environmental Center
USAE-WES	U.S. Army Engineers Waterways Experiment Station
USAF	U.S. Air Force
USACERL	See CERL
USACRREL	See CRREL
USAMC	U.S. Army Materiel Command
USN	U.S. Navy
USATHAMA	U.S. Army Toxic and Hazardous Material Agency, now USAEC
UST	Underground Storage Tank
UV	Ultraviolet
UXO	Unexploded Ordnance
VOC	Volatile Organic Compound
WESTON	Roy F. Weston, Inc.
yd^3	Cubic Yards

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Section 1
INTRODUCTION

✍ 1.1 OBJECTIVES

The goal of remedial investigation/feasibility studies (RI/FS) and hazardous waste cleanup projects is to obtain enough information on th site to consider and select practicable remedial alternatives. Gathering this information can require considerable time, effort, and finances. In some cases, it is possible to focus on specific remedies that have been proven under similar conditions.

FIGURE 1-1 REDUCTION OF DATA NEEDS BY SCREENING AND PRESUMPTIVE REMEDIES

This guide is intended to be used to screen and evaluate candidate cleanup technologies for contaminated installations and waste sites in order to assist

remedial project managers (RPMs) in selecting a remedial alternative. To reduce data collection efforts and to focus the remedial evaluation steps, information on widely used and presumptive remedies is provided. Figure 1-1 illustrates the trend toward reduction in the degree of site characterization through screening and the use of presumptive remedies.

Presumptive remedies, as established by the U.S. Environmental Protection Agency (EPA), are preferred technologies for common categories of sites, based on historical patterns of remedy selection and EPA's scientific and engineering evaluation of performance data on technology implementation. Use of presumptive remedies will allow a RPM to focus on one or two alternatives: decreasing the site characterization data needs and focusing the remedial evaluation steps, resulting in less time and effort. Conversely, sites with extensive data needs will require a more thorough characterization and evaluation of many remedial alternatives.

The unique approach used to prepare this guide was to review and compile the collective efforts of several U.S. Government agencies into one compendium document. For each of several high-frequency of occurrence types of sites, the guide enables the reader to:

- Screen for possible treatment technologies.
- Distinguish between emerging and mature technologies.
- Assign a relative probability of success based on available performance data, field use, and engineering judgment.

This guide allows the reader to gather essential descriptive information on the respective treatment technologies. It incorporates cost and performance data to the maximum extent available and focuses primarily on demonstrated technologies; however, emerging technologies may be more appropriate in some cases, based upon site conditions and requirements. The final selection of a technology usually requires site-specific treatability studies. As more is learned about developing technologies, this guide will be updated accordingly. These technologies are applicable at all types of site cleanups: Superfund, DOD, DOE, RCRA, state, private, etc.

A primary audience for this document is RPMs and their supporting contractors and consultants. This audience also includes the U.S. Department of Defense (DOD) installation commanders, environmental coordinators, trainers at DOD and federal installations, agencies, researchers, Congressional staffers, public interest groups, and private sector consultants.

✍ 1.2 BACKGROUND

One of the distinctive attributes of environmental technology is that the state-of-the-art continually changes. To ensure that services and agencies within DOD, the U.S. Department of Energy (DOE), the U.S. Department of the Interior (DOI), and EPA have the latest information regarding the status of environmentally applicable technologies, technology transfer documents are periodically updated and published. These publications provide a reference to site characterization, installation restoration (IR), hazardous waste control, and pollution prevention technologies. They increase technology awareness, enhance coordination, and aid in preventing duplication of environmental technology development efforts. Information contained in these documents is obtained from federal research facilities as well as from private-sector vendors involved in research and development and implementation of methods to characterize and clean up contaminated sites and materials.

A list of U.S. Government reports documenting innovative and conventional site remediation technologies that are incorporated into this guide is presented in Table 1-1. These documents are described in greater detail in Appendix E.

TABLE 1-1
U.S. GOVERNMENT REMEDIATION TECHNOLOGY REPORTS INCORPORATED INTO THIS GUIDE

Government Sponsoring Agency	Title
U.S. Army Environmental Center (USAEC)	*Installation Restoration and Hazardous Waste Control Technologies,* Third Edition, November 1992
Federal Remediation Technologies Roundtable (FRTR)	*Synopses of Federal Demonstrations of Innovative Site Remediation Technologies,* Third Edition, August 1993 *Accessing Federal Data Bases for Contaminated Site Clean-Up Technologies*, Third Edition, September 1993 *Federal Publications on Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation*, Third Edition, September 1993
EPA	*The Superfund Innovative Technology Evaluation (SITE) Program: Technology Profiles,* Sixth Edition, November 1993
DOE	*Technology Catalogue,* First Edition, February 1994
U.S. Air Force (USAF), EPA	*Remediation Technologies Screening Matrix and Reference Guide,* Version I, July 1993

Government Sponsoring Agency	Title
USAF	*Remedial Technology Design, Performance, and Cost Study,* July 1992
California Base Closure Environmental Committee	*Treatment Technologies Applications Matrix for Base Closure Activities*, November 1993
EPA/U.S. Navy	*EPA/Navy CERCLA Remedial Action Technology Guide,* November 1993

✍ 1.3 HOW TO USE THIS DOCUMENT

This guide contains six sections:

1. Introduction
2. Contaminant Perspectives
3. Treatment Perspectives
4. Treatment Technology Profiles
5. References
6. Index

Section 1, the **Introduction**, presents objectives, background information, guidance on how to use this document, and limitations on its use.

Sections 2 through 5 are intended to aid an RPM in performing the RI/FS or equivalent process (see Figure 1-2).

FIGURE 1-2 THE ROLE OF THIS DOCUMENT IN THE RI/FS PROCESS (OR EQUIVALENT)

Section 2, Contaminant Perspectives, addresses contaminant properties and behavior and preliminarily identifies potential treatment technologies based on their applicability to specific contaminants and media. This section describes five contaminant groups, as determined by the DOD Environmental Technology Transfer Committee (ETTC):

- Volatile organic compounds (VOCs).
- Semivolatile organic compounds (SVOCs).
- Fuels.
- Inorganics.
- Explosives.

Treatment technologies capable of treating a contaminant group are presented in a technology screening matrix for each of the five contaminant groups. The most commonly used technologies are discussed in the text for that contaminant in soil, sediment, and sludge, and in groundwater, surface water, and leachate. (The discussion of VOCs also addresses air emissions and off-gases.) If presumptive treatments are available for the contaminants, they are identified in this section. Section 2 will also aid in scoping the RI/FS by identifying data needs in order to characterize contamination in media and by identifying potential contaminants based

on historical usage of the site.

Section 3, Treatment Perspectives, provides an overview of each treatment process group and how it will impact technology implementation [e.g., ex situ soil treatment (as compared to in situ soil treatment) leads to additional cost, handling, permitting, and safety concerns as a result of excavation]. The treatment process groups discussed include the following 13 treatment areas:

- In situ biological treatment for soil, sediment, and sludge.
- In situ physical/chemical treatment for soil, sediment, and sludge.
- In situ thermal treatment for soil, sediment, and sludge.
- Ex situ biological treatment for soil, sediment, and sludge.
- Ex situ physical/chemical treatment for soil, sediment, and sludge.
- Ex situ thermal treatment for soil, sediment, and sludge.
- Other treatments for soil, sediment, and sludge.
- In situ biological treatment for groundwater, surface water, and leachate.
- In situ physical/chemical treatment for groundwater, surface water, and leachate.
- Ex situ biological treatment for groundwater, surface water, and leachate.
- Ex situ physical/chemical treatment for groundwater, surface water, and leachate.
- Other treatments for groundwater, surface water, and leachate.
- Air emissions/off-gas treatment.

Section 3 will aid the RPM in screening potential treatment technologies based on site requirements and in combining potential treatment technologies into remedial action alternatives for the overall site. A comprehensive screening matrix listing each of the treatment technologies contained in this document is presented in this section. Information on completed projects in these treatment process areas has been presented in tables extracted from the *Innovative Treatment Technologies:*

Annual Status Report (EPA, 1993), and the *Synopses of Federal Demonstrations of Innovative Site Remediation Technologies* (FRTR, 1993).

Section 4, Treatment Technology Profiles, enables the RPM to perform a more detailed analysis of the remedial action alternatives. The treatment technology descriptions include the following information:

- Description.
- Applicability.
- Limitations.
- Data needs.
- Performance data.
- Cost.
- Site information (typically, three representative sites with the most complete information were chosen).
- Points of contact (typically, three contacts representing different government agencies were extracted from the source documents).
- References (typically, five published public sector reports were extracted from the source documents).

Information contained in these profiles was extracted from the source documents, followed by an extensive review by the DOD ETTC. The cost data are provided solely as a general indicator of the treatment cost and should be verified with specific technology vendors, independent cost estimates, and past experience. Specific technology vendors may be identified by accessing the Vendor Information System for Innovative Treatment Technologies (VISITT) data base. Although the VISITT data base does not include information on vendors for solidification/stabilization, information on these technologies was added. Information on this data base and a current (1994) vendor list printout are in Appendix A.

Section 5, References, presents a list of documents that contain additional information on treatment technologies. Information on where to obtain federal documents is provided in Subsection 5.1. Subsection 5.2 presents references on innovative treatment technologies sorted by technology type. Subsection 5.3

presents a comprehensive list of sources of additional information (including the references presented in Section 4 for each treatment technology), which is a compilation of all published references that were presented in each of the source documents.

Section 6, Index, provides a 100-keyword index to this document.

The five appendices to this document contain the following information:

- **Appendix A, Vendor Information System for Innovative Treatment Technologies (VISITT).** This appendix provides a brief description of the VISITT data base and a current printout of the vendors of technologies included in this guide, including the company name and telephone number.

- **Appendix B, DOE Site Remediation Technologies by Waste Contaminant Matrix *and* Completed Site Demonstration Program Projects as of October 1993.** Table B-1 provides a complete listing of the treatment technologies provided in the DOE *Technology Catalogue* organized by the contaminant applicability. Table B-2 provides a listing of completed SITE Demonstration Programs reproduced from *Superfund Innovative Technology Evaluation Program, Technology Profiles*, Sixth Edition.

- **Appendix C, Federal Data Bases and Additional Information Sources**. This appendix provides a listing of sources of follow-up information, including data bases, document printing offices, and information centers.

- **Appendix D, Parameters Affecting Treatment Cost or Performance.** This appendix documents the results of an FRTR meeting on 26 October and 9 November 1993 to review related activities, identify information needs, and develop a strategy for documentation of cost and performance information.

- **Appendix E, Description of Source Documents**. This appendix provides a description of each of the government documents that were the origin of this compendium document. Many other sources not listed here were also used to a lesser extent. These additional sources are presented in Section 5, References.

The two attachments to this document contain the following information.

- **Attachment 1, Treatment Technologies Screening Matrix.** This attachment provides an overall summary of treatment technologies with their development status, availability, residuals produced, treatment train,

contaminants treated, system reliability/maintainability, cleanup time, overall cost, and O&M/capital intensive status. Rating codes (better, average, or worse) have been provided for applicable parameters.

- **Attachment 2, Remediation Technology Application and Cost Guide.** This attachment consists of a summary table presented on three foldout pages. The table provides a concise summary of remedial technology applications and costs for remedial strategies. The information in the table includes remedial strategy, media, remedial technology, conditions favorable to use, unit cost range, major cost drivers, and additional comments.

✍ 1.4 REQUIREMENTS TO CONSIDER TECHNOLOGY'S IMPACTS ON NATURAL RESOURCES

Because the use of various treatment technologies can have a significant impact on a site's natural resources, careful consideration of these effects should be made when selecting technologies for cleanup. Following a site cleanup, both the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Oil Pollutant Act (OPA) require that residual natural resource injuries be assessed by federal, state, and/or tribal natural resource trustees, and restoration of those injured resources are to be accomplished. Restoration is generally defined as returning natural resources to their pre-incident conditions.

Through coordination among agencies responsible for cleanup and restoration (natural resource trustees, such as U.S. Geological Survey, U.S. Fish and Wildlife, and State Department of Natural Resources personnel), cleanup technologies can be selected that minimize the residual injury that will need to be dealt with in the Natural Resources Damage Assessment and Restoration process. To ensure that such concerns are properly considered in the selection of cleanup technologies, the DOI advises that the RPM contact the local representative of a site's resource trustee **as early as possible** in the selection process (e.g., the Fish and Wildlife Service). Such cooperative efforts should improve efficiency and reduce overall costs of the combined cleanup/restoration processes.

✍ 1.5 CAUTIONARY NOTES

This document is not designed to be used as the sole basis for remedy selection. This guide and supporting information should be used only as a guidance document, and the exclusion or omission of a specific treatment technology does not necessarily mean that a technology is not applicable to a site.

It is important to recognize that the amount of information about technologies is rapidly growing. Information currently contained in this document was primarily excerpted from 1992, 1993, and 1994 source documents. This information was

subsequently updated to the maximum extent possible through the interagency review process used in preparing this handbook. After identifying potentially applicable technologies, however, it is essential that prior to remedy selection RPMs consult the individual treatment technology vendor and/or government point of contact to evaluate technology, cost, and performance data in light of the most up-to-date information and site-specific conditions. Additional information to support identification and analysis of potentially applicable technologies can be obtained by consulting published references and contacting technology experts. The final selection of technology usually requires additional site-specific treatability studies. The reader is encouraged to keep information current by adding new information as it becomes available.

✍ 1.6 MAIL-IN SURVEY

This mail-in-survey form serves as the primary opportunity for providing feedback on this document. By sending their feedback, readers will get the opportunity to be involved in future update and review efforts. Readers may send their comments by mail or transmit electronically. The Internet address is provided on the form for electronic responses.

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Section 2
CONTAMINANT PERSPECTIVES

Information on classes and concentrations of chemical contaminants, how they are distributed through the site, and in what media they appear is essential to begin the preselection of treatment technologies. In this document, contaminants have been separated into five contaminant groups as follows:

- Volatile organic compounds (VOCs).
- Semivolatile organic compounds (SVOCs).
- Fuels.
- Inorganics (inclding radioactive elements).
- Explosives.

This section presents a discussion of the properties and behaviors of the contaminant groups, followed by a discussion of the most commonly used treatment technologies available for that contaminant group. (Less commonly used treatment technologies are identified in the treatment technology screening matrix and may be found in Section 4.) Each discussion of the contaminant groups is divided into two media classifications: (1) soil, sediment, and sludge and (2) groundwater, surface water, and leachate. (The VOC contamination section additionally addresses air emissions and off-gases.)

A matrix summarizing treatment technology information is presented for each contaminant group. It should be noted that these technologies are not necessarily effective at treating all contaminants in the contaminant group. Information summarized includes the development status (full-scale or pilot-testing), the use rating (widely/commonly used or limited use), the applicability rating (better, average, or below average), and the treatment function (destruction, extraction, or immobilization). The "use" rating was determined from information presented in the *Treatment Technologies Applications Matrix for Base Closure Activities* (California Base Closure Environmental Committee, 1993). The applicability rating was determined from information presented in the first edition of this document (EPA, USAF, 1993). **Please note,** a treatment technology may be applicable to treat a specific contaminant group, but may not be widely used because of factors such as cost, public acceptance, or implementability. All information presented in these matrices has been subjected to rigorous ETTC member review and amended where appropriate for the purposes of this document.

Subsection 2.1 presents a discussion of the presumptive remedy process.

Subsection 2.2, Data Requirements, addresses the specific data elements required to characterize each medium and the impact on technology selection. Discussion of each of the five contaminant groups appears in Subsections 2.3 to 2.7.

Pilot scale describes all techniques not yet developed to full-scale, including those still in the bench-scale phase of development.

✍ 2.1 PRESUMPTIVE REMEDIES

A presumptive remedy is a technology that EPA believes, based upon its past experience, generally will be the most appropriate remedy for a specified type of site. EPA is establishing presumptive remedies to accelerate site-specific analysis of remedies by focusing the feasibility study efforts. EPA expects that a presumptive remedy, when available, will be used for all CERCLA sites except under unusual circumstances.

Accordingly, EPA has determined that, when using presumptive remedies, the site characterization data collection effort can be limited, and the detailed analysis can be limited to the presumptive remedies (in addition to the no-action alternative), thereby streamlining that portion of the FS. Supporting documentation should be included in the Administrative Record for all sites that use the presumptive remedy process to document the basis for eliminating the site-specific identification. This supporting documentation is provided in the presumptive remedy document itself.

Circumstances where a presumption remedy may not be used include unusual site soil characteristics or mixtures of contaminants not treated by the remedy, demonstration of significant advantages of alternate (or innovative) technologies over the presumptive remedies, or extraordinary community and state concerns. The use of nonpresumptive-remedy technologies, or the absence of a presumptive remedy entirely, does not render the selected treatment technology less effective. The presumptive remedy is simply an expedited approval process, not the only technically feasible alternative. If such circumstances are encountered, additional analyses may be necessary or a more conventional detailed RI/FS may be performed.

There are currently three published presumptive remedy documents:

- *Presumptive Remedies: Policies and Procedures* (EPA, 1993). EPA Document No. 540-F-93-047.

- *Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites with Volatile Organic Compounds in Soils* (EPA, 1993). EPA Document No. 540-F-93-048.

- *Presumptive Remedy for CERCLA Municipal Landfill Sites* (EPA, 1993). EPA Document No. 540-F-93-035.

Additional presumptive remedies are currently being determined for wood treating,

contaminated groundwater, PCB, coal gas, and grain storage sites.

In addition, there is a desire among various governmental agencies to expand this process, or develop a parallel process for their remediation projects. For example, the U.S. Air Force Center for Environmental Excellence/Technology Transfer Division (AFCEE/ERT) advocates the use of the following remedies:

- Bioventing for fuel-contaminated soils.
- A combination of vacuum-enhanced free product recovery and bioremediation for light non-aqueous phase liquid (LNAPL) floating product.
- Natural attenuation for petroleum hydrocarbon-contaminated groundwater.

✍ 2.2 DATA REQUIREMENTS

For all remedial investigation and cleanup sites, the vertical and horizontal contaminant profiles should be defined as much as possible. Information on the overall range and diversity of contamination across the site is critical to treatment technology selection. Obtaining this information generally requires taking samples and determining their physical and chemical characteristics. If certain types of technologies are candidates for use, the specific data needs for these technologies can be met during the initial stages of the investigation. The data requirements are technology-specific and not risk-based. The following subsections present a partial list of the characteristics and rationale for collection of treatment technology preselection data for each of the three media. A matrix of characteristics affecting treatment cost or performance versus technologies is provided in Appendix D, which is also an effort by ETTC.

✍ 2.2.1 Data Requirements for Soil, Sediment, and Sludge

Site soil conditions frequently limit the selection of a treatment process. Process-limiting characteristics such as pH or moisture content may sometimes be adjusted. In other cases, a treatment technology may be eliminated based upon the soil classification (e.g., particle-size distribution) or other soil characteristics.

Soils are inherently variable in their physical and chemical characteristics. Usually the variability is much greater vertically than horizontally, resulting from the variability in the processes that originally formed the soils. The soil variability, in turn, will result in variability in the distribution of water and contaminants and in the ease with which they can be transported within, and removed from, the soil at a particular site.

Many data elements are relatively easy to obtain, and in some cases more than one test method exists. Field procedures are performed for recording data or for collecting samples to determine the classification, moisture content, and permeability of soils across a site. Field reports describing soil variability may lessen the need for large numbers of samples and measurements to describe site characteristics. Common field information-gathering often includes descriptions of

natural soil exposures, weathering that may have taken place, cross-sections, subsurface cores, and soil sampling. Such an effort can sometimes identify probable areas of past disposal through observation of soil type differences, subsidence, and backfill.

Soil **particle-size distribution** is an important factor in many soil treatment technologies. In general, coarse, unconsolidated materials, such as sands and fine gravels, are easiest to treat. Soil washing may not be effective where the soil is composed of large percentages of silt and clay because of the difficulty of separating the adsorbed contaminants from fine particles and from wash fluids. Fine particles also can result in high particulate loading in flue gases from rotary kilns as a result of turbulence. Heterogeneities in soil and waste composition may produce nonuniform feedstreams for many treatment processes that result in inconsistent removal rates. Fine particles may delay setting and curing times and can surround larger particles, causing weakened bonds in solidification/stabilization processes. Clays may cause poor performance of the thermal desorption technology as a result of caking. High silt and clay content can cause soil malleability and low permeability during steam extraction, thus lowering the efficiency of the process.

Soil homogeneity and isotropy may impede in situ technologies that are dependent on the subsurface flow of fluids, such as soil flushing, steam extraction, vacuum extraction, and in situ biodegradation. Undesirable channeling may be created in alternating layers of clay and sand, resulting in inconsistent treatment. Larger particles, such as coarse gravel or cobbles, are undesirable for vitrification and chemical extraction processes and also may not be suitable for the stabilization/solidification technology.

The **bulk density** of soil is the weight of the soil per unit volume, including water and voids. It is used in converting weight to volume in materials handling calculations, and can aid in determining if proper mixing and heat transfer will occur.

Particle density is the specific gravity of a soil particle. Differences in particle density are important in heavy mineral/metal separation processes (heavy media separation). Particle density is also important in soil washing and in determining the settling velocity of suspended soil particles in flocculation and sedimentation processes.

Soil **permeability** is one of the controlling factors in the effectiveness of in situ treatment technologies. The ability of soil-flushing fluids (e.g., water, steam, solvents, etc.) to contact and remove contaminants can be reduced by low soil permeability or by variations in the permeability of different soil layers. Low permeability also hinders the movement of air and vapors through the soil matrix. This can lessen the volatilization of VOCs in SVE processes. Similarly, nutrient solutions, used to accelerate in situ bioremediation, may not be able to penetrate low-permeability soils in a reasonable time. Low permeability may also limit the effectiveness of in situ vitrification by slowing vapor releases.

High soil **moisture** may hinder the movement of air through the soil in vacuum extraction systems and may cause excavation and material transport problems. High soil moisture also affects the application of vitrification and other thermal treatments by increasing energy requirements, thereby increasing costs. On the other hand, increased soil moisture favors in situ biological treatment.

The **pH** of the waste being treated may affect many treatment technologies. The solubility of inorganic contaminants is affected by pH; high pH in soil normally lowers the mobility of inorganics in soil. The effectiveness of ion exchange and flocculation processes may be negatively influenced by extreme pH ranges. Microbial diversity and activity in bioremediation processes also can be affected by extreme pH ranges.

E_h is the oxidation-reduction (redox) potential of the material being considered when oxidation-reduction types of chemical reactions are involved. Examples of these types of reactions include alkaline chlorination of cyanides, reduction of hexavalent chromium with sulfite under acidic conditions, aerobic oxidation of organic compounds into CO_2 and H_2O, or anaerobic decomposition of organic compounds into CO_2 and CH_4. Maintaining a low E_h in the liquid phase enhances anaerobic biologic decomposition of certain halogenated organic compounds.

K_{ow} (the octanol/water partition coefficient) is defined as the ratio of a chemical's concentration in the octanol phase to its concentration in the aqueous phase of a two-phase octanol/water system. K_{ow} is a key parameter in describing the fate of an organic chemicals in environmental systems. It has been found to be related to the water solubility, soil/sediment adsorption coefficient, and the bioconcentration factors for aquatic species. The physical meaning of K_{ow} is the tendency of a chemical to partition itself between an organic phase [e.g., polycyclic aromatic hydrocarbons (PAHs) in a solvent] and an aqueous phase. Chemicals that have a low K_{ow} value (<10) may be considered relatively hydrophilic; they tend to have a high water solubility, small soil/sediment adsorption coefficients, and small bioconcentration factors for aquatic life. Conversely, a chemical with a large K_{ow} ($>10^4$) is considered hydrophobic and tends to accumulate at organic surfaces, such as on humic soil and aquatic species.

Humic content (organic fraction) is the decomposing part of the naturally occurring organic content of the soil. High humic content will act to bind the soil, decreasing the mobility of organics and decreasing the threat to groundwater; however, high humic content can inhibit soil vapor extraction (SVE), steam extraction, soil washing, and soil flushing as a result of strong adsorption of the contaminant by the organic material. Reaction times for chemical dehalogenation processes can be increased by the presence of large amounts of humic materials. High organic content may also exert an excessive oxygen demand, adversely affecting bioremediation and chemical oxidation.

Total organic carbon (TOC) provides an indication of the total organic material present. It is often used as an indicator (but not a measure) of the amount of waste

available for biodegradation. TOC includes the carbon both from naturally-occurring organic material and organic chemical contaminants; however, all of it competes in reduction/oxidation reactions leading to the need for larger amounts of chemical reagents than would be required by the contaminants alone.

Measurement of volatile hydrocarbons, oxygen (O_2), and carbon dioxide (CO_2) at sites containing biodegradable contaminants like petroleum hydrocarbons or sites with high TOC is useful in further delineating and confirming areas contaminated as well as identifying the strong potential for bioremediation by bioventing. In addition, if the use of thermal combustion or certain oxidation systems is planned for off-gas treatment of extracted vapors, then adequate supply of air or oxygen will have to be provided to efficiently operate these systems.

Biochemical oxygen demand (BOD) provides an estimate of the aerobic biological decomposition of the soil organics by measuring the oxygen consumption of the organic material that can be readily or eventually biodegraded. **Chemical oxygen demand** (COD) is a measure of the oxygen equivalent of the organic content in a sample that can be oxidized by a strong chemical oxidant such as dichromate or permanganate. Sometimes COD and BOD can be correlated, and the COD/BOD ratio can give another indication of biological treatability or treatability by chemical oxidation. COD is also useful in assessing the applicability of wet air oxidation.

One of the major determining factors in the fate of biodegradable contaminants is the availability of sufficient **electron acceptors** (i.e., oxygen, nitrate, iron, manganese, sulfate, etc.) to support biodegradation. Internal tracers, such as trimethyl and tetramethylbenzenes, are normal constituents of fuels that are significantly less biodegradable than benzene, toluene, ethylbenzene, and xylenes (BTEX), yet have very similar transport characteristics. Thus, these "internal tracers" can be detected downgradient of the remediation area, thereby demonstrating that monitoring wells are properly placed and the absence of BTEX is a result of biodegradation. The concentrations of these tracers can also provide a basis to correct for the contribution of dilution to contaminant attenuation.

Oil and grease, when present in a soil, will coat the soil particles. The coating tends to weaken the bond between soil and cement in cement-based solidification. Similarly, oil and grease can also interfere with reactant-to-waste contact in chemical reduction/oxidation reactions, thus reducing the efficiency of those reactions.

✍ 2.2.2 Data Requirements for Groundwater, Surface Water, and Leachate

It is common for groundwater to be contaminated with the water soluble substances found in overlying soils. Many of the required data elements are similar, e.g., pH, TOC, BOD, COD, oil and grease, contaminant identification and quantification, and soil and aquifer characterization. Additional water quality monitoring data elements include hardness, ammonia, total dissolved solids, and metals content (e.g., iron, manganese). Knowledge of the site conditions and history may contribute to selecting a list of contaminants and cost-effective analytical methods.

As with soils, the **pH** of groundwater is important in determining the applicability of many treatment processes. Often, the pH must be adjusted before or during a treatment process. Low pH can interfere with chemical reduction/oxidation processes. Extreme pH levels can limit microbial diversity and hamper the application of both in situ and aboveground applications of biological treatment. Contaminant solubility and toxicity may be affected by changes in pH. The species of metals and inorganics present are influenced by the pH of the water, as are the type of phenolic and nitrogen-containing compounds present. Processes such as carbon adsorption, ion exchange, and flocculation may be affected by pH.

E_h helps to define, with pH, the state of oxidation-reduction equilibria in aqueous wastestreams. As noted earlier in the soils section, maintaining anaerobiosis (low E_h) enhances decomposition of certain halogenated compounds.

BOD, COD, and TOC measurements in contaminated water, as in soils, provide indications of the biodegradable, chemically oxidizable, or combustible fractions of the organic contamination, respectively. These measurements are not interchangeable, although correlations may sometimes be made in order to convert the more precise TOC and/or COD measurements to estimates of BOD.

Oil and grease, even in low concentrations, may require pretreatment to prevent clogging of primary treatment systems (i.e., ion exchange resins, activated carbon systems, or other treatment system components). Oil and grease may be present in a separate phase in groundwater.

Suspended solids can cause clogging of primary treatment systems and may require pretreatment of the wastestream through coagulation/sedimentation and/or filtration. **Major anions** (chloride, sulfate, phosphate, and nitrate) and **cations** (calcium, magnesium, sodium, and potassium) are important for evaluating in situ geochemical interactions, contaminant speciation, and water-bearing zone migration. **Iron concentrations** should be measured to determine the potential for precipitation upon aeration. **Alkalinity** should also be measured when analyzing for major anions and cations.

In addition to chemical parameters, geologic and hydrologic information is usually needed to plan and monitor a groundwater remediation. A detailed **geologic characterization** is usually needed to assess the uniformity (homogeneity and isotropy) of the subsurface hydrostratigraphy. The average **rate of groundwater flow** can be estimated from the hydraulic conductivity, hydraulic gradient, and effective porosity. **Hydraulic gradient** is calculated from groundwater elevations measured in monitor wells. **Effective porosity** is usually assumed based on ranges of values cited in scientific literature or estimated from pumping tests. **Hydraulic conductivity** is usually estimated from slug tests or pumping tests. If an active groundwater extraction system is being planned, **safe aquifer yields** and **boundary conditions** must be established. These parameters require that pumping tests be conducted.

✍ 2.2.3 Data Requirements for Air Emissions/Off-Gases

Predictive modeling may be useful in estimating emissions from a site or treatment system. An appropriate theoretical model is selected to represent the system (e.g., SVE treatment, incinerator, etc.), and site and contaminant information is used to estimate gross emissions. Because many variables affect emission rates, this approach is limited by the representativeness of the model and by the input used. This approach is usually used as a screening-level or pre-design evaluation. Site-specific data to support planning or technology selection activities (e.g., health risk assessments, pilot-scale studies) should be performed prior to actual implementation.

Emissions of VOCs and particulate matter during site disturbances, such as excavation, may be several orders of magnitude greater than the emission levels of an undisturbed site. The potential air emissions from the undisturbed and disturbed site must be understood before developing a site mitigation strategy. EPA has developed a systematic approach, called an Air Pathway Analysis (APA), for determining what air contaminants are present and at what level these compounds may be released into the atmosphere. The APA method is outlined in a four-volume series (*Air Superfund National Technical Guidance Study Series*, EPA, 1989).

Emissions from treatment systems (e.g., SVE or incinerators, etc.) may be approximated by using soil contaminant concentrations and flow or throughput rate.

If the use of thermal combustion or certain oxidation systems is planned for off-gas treatment of extracted vapors, then an adequate supply of air/oxygen will have to be provided for in order to operate these efficiently.

Information regarding the concentration and permeability/percent flow at discrete vertical intervals is extremely useful in optimized recovery from the regions of highest contaminant mass/removal potential. In other words, if 90% of the contaminant mass is being extracted from only 5% of the vertical interval, then off-gas treatment is biased by the large contribution of uncontaminated soil gas. Thus, changes in screened intervals, flow rates, mass transfer rates, and residual contaminant composition over time can dramatically affect off-gas treatment and should be evaluated.

✍ 2.3 VOLATILE ORGANIC COMPOUNDS (VOCs)

Sites where VOCs may be found include burn pits, chemical manufacturing plants or disposal areas, contaminated marine sediments, disposal wells and leach fields, electroplating/metal finishing shops, firefighting training areas, hangars/aircraft maintenance areas, landfills and burial pits, leaking collection and system sanitary lines, leaking storage tanks, radioactive/mixed waste disposal areas, oxidation ponds/lagoons, paint stripping and spray booth areas, pesticide/herbicide mixing areas, solvent degreasing areas, surface impoundments, and vehicle maintenance areas. Potentially applicable remediation technologies are presented in Table 2-1. Typical VOCs (excluding fuels, BTEX, and gas phase contaminants, which are

presented in Subsection 2.5) encountered at many sites include the following:

- Halogenated VOCs

  - Bromodichloromethane
  - Bromoform
  - Bromomethane
  - Carbon tetrachloride
  - Chlorodibromomethane
  - Chloroethane
  - Chloroform
  - Chloromethane
  - Chloropropane
  - Cis-1,2-dichloroethylene
  - Cis-1,3-dichloropropene
  - Dibromomethane
  - 1,1-Dichloroethylene
  - Dichloromethane
  - 1,2-Dichloropropane
  - Ethylene dibromide
  - Fluorotrichloromethane (Freon 11)
  - Hexachloroethane
  - Methylene chloride
  - Monochlorobenzene
  - 1,1,2,2-Tetrachloroethane
  - Tetrachloroethylene (Perchloroethylene) (PCE)
  - 1,2-Trans-dichloroethylene

TABLE 2-1 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF VOLATILE ORGANIC COMPOUNDS

NOTE: Specific site and contaminant characteristics may limit the applicability and effectiveness of any of the technologies and treatments listed below. This matrix is optimistic in nature and should always be used in conjunction with the *referenced text sections*, which contain additional information that can be useful in identifying potentially applicable technologies.

Technology (Text Section and Title)		Development Status	Use Rating	Applicability[a]	Technology Function[a]
SOIL, SEDIMENT, AND SLUDGE					
3.1	**IN SITU BIOLOGICAL TREATMENT**				
4.1	Biodegradation	Full	Limited	Better	Destruct
4.2	Bioventing	Full	Limited	Better	Destruct
3.2	**IN SITU PHYSICAL/CHEMICAL TREATMENT**				
4.5	Soil Flushing	Pilot	Limited	Better	Extract
4.6	Soil Vapor Extraction	Full	Wide[b]	Better	Extract
3.3	**IN SITU THERMAL TREATMENT**				
4.8	Thermally Enhanced SVE	Full	Limited	Average	Extract
4.9	In Situ Vitrification	Pilot	Limited	Below Avg.	Extract/Destru
3.4	**EX SITU BIOLOGICAL TREATMENT (ASSUMING EXCAVATION)**				
4.10	Composting	Full	Limited	Better	Destruct
4.11	Cont. Solid Phase Bio.	Full	Limited	Better	Destruct
4.12	Landfarming	Full	Limited	Better	Destruct
4.13	Slurry Phase Bio.	Full	Limited	Better	Destruct
3.5	**EX SITU PHYSICAL/CHEMICAL TREATMENT (ASSUMING EXCAVATION)**				
4.14	Chemical	Full	Limited	Average	Destruct
4.15	Dehalogenation (BCD)	Full	Limited	Average	Destruct
4.16	Dehalogenation	Full	Limited	Average	Destruct
4.17	Soil Washing	Full	Limited	Average	Extract
4.18	Soil Vapor Extraction	Full	Limited	Better	Extract
4.20	Solvent Extraction	Full	Limited	Average	Extract
3.6	**EX SITU THERMAL TREATMENT (ASSUMING EXCAVATION)**				
4.21	High Temp. Thermal	Full	Limited	Average	Extract
4.23	Incineration	Full	Wide[b]	Average	Destruct
4.24	Low Temp. Thermal	Full	Wide[b]	Better	Extract
4.26	Pyrolysis	Pilot	Limited	Below Avg.	Destruct
4.27	Vitrification	Full	Limited	Average	Ext./Destruct
3.7	**OTHER TREATMENT**				
4.28	Excavation and Off-Site	NA	Limited	Average	Extract/Immob
4.29	Natural Attenuation	NA	Limited	Better	Destruct
GROUNDWATER, SURFACE WATER, AND LEACHATE					
3.8	**IN SITU BIOLOGICAL TREATMENT**				
4.30	Co-Metabolic Treatment	Pilot	Limited	Better	Destruct
4.31	Nitrate Enhancement	Pilot	Limited	Better	Destruct
4.32	Oxygen Enhance. w/Air	Full	Limited	Better	Destruct
4.33	Oxygen Enhance. w/H_2O_2	Full	Limited	Better	Destruct
3.9	**IN SITU PHYSICAL/CHEMICAL TREATMENT**				
4.34	Air Sparging	Full	Limited	Better	Extract
4.36	Dual Phase Extraction	Full	Limited	Better	Extract
4.38	Hot Water or Steam	Pilot	Limited	Average	Extract
4.40	Passive Treatment Walls	Pilot	Limited	Better	Destruct
4.41	Slurry Walls	Full	Limited	Average	Immob.
4.42	Vacuum Vapor Extraction	Pilot	Limited	Better	Extract
3.10	**EX SITU BIOLOGICAL TREATMENT (ASSUMING PUMPING)**				
4.43	Bioreactors	Full	Limited	Better	Destruct
3.11	**EX SITU PHYSICAL/CHEMICAL TREATMENT (ASSUMING PUMPING)**				
4.44	Air Stripping	Full	Wide	Better	Extract
4.47	Liquid Phase Carbon	Full	Wide	Better	Extract

TABLE 2-1 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF VOLATILE ORGANIC COMPOUNDS

NOTE: Specific site and contaminant characteristics may limit the applicability and effectiveness of any of the technologies and treatments listed below. This matrix is optimistic in nature and should always be used in conjunction with the *referenced text sections*, which contain additional information that can be useful in identifying potentially applicable technologies.

	4.49 UV Oxidation	Full	Limited	Better	Destruct
3.12	**OTHER TREATMENT**				
	4.50 Natural Attenuation	NA	Limited	Better	Destruct
3.13	**AIR EMISSIONS/OFF-GAS**				
	4.51 Biofiltration	Full	Limited	Better	Ext./Destruct
	4.52 High Energy Corona	Pilot	Limited	Better	Destruct
	4.53 Membrane Separation	Pilot	Limited	Better	Extract
	4.54 Oxidation	Full	Wide	Better	Destruct
	4.55 Vapor Phase Carbon	Full	Wide	Better	Extract

[a]The following rankings are discussed in Table 3-1 and Figure 3-1. [b]Presumptive remedy.

- 1,1-Dichloroethane
- 1,2-Dichloroethane
- 1,2-Dichloroethene
- Trichloroethylene (TCE)
- 1,2,2-trifluoroethane (Freon 113)
- Trans-1,3-dichloropropene
- 1,1,1-Trichloroethane
- 1,1,2-Trichloroethane
- Vinyl chloride

· Nonhalogenated VOCs

- Acetone
- Acrolein
- Acrylonitrile
- n-Butyl alcohol
- Carbon disulfide
- Cyclohexanone
- Ethyl acetate
- Ethyl ether
- Isobutanol
- Methanol
- Methyl ethyl ketone (MEK)
- Methyl isobutyl ketone
- 4-Methyl-2-pentanone
- Styrene
- Tetrahydrofuran
- Vinyl acetate

✍ 2.3.1 Properties and Behavior of VOCs

An important consideration when evaluating a remedy is whether the compound is halogenated or nonhalogenated. A halogenated compound is one onto which a halogen (e.g., fluorine, chlorine, bromine, or iodine) has been attached. Typical halogenated and nonhalogenated VOCs have been listed at the beginning of Subsection 2.3. The nature of the halogen bond and the halogen itself can significantly affect performance of a technology or require more extensive treatment than for nonhalogenated compounds.

As an example, consider bioremediation. Generally, halogenated compounds are less amenable to this form of treatment than nonhalogenated compounds. In addition, the more halogenated the compound (i.e., the more halogens attached to it), the more refractive it is toward biodegradation. As another example, incineration of halogenated compounds requires specific off-gas and scrubber water treatment for the halogen in addition to the normal controls that are implemented for nonhalogenated compounds.

Therefore, the vendor of the technology being evaluated must be informed whether the compounds to be treated are halogenated or nonhalogenated. In most instances, the vendor needs to know the specific compounds involved so that modifications to technology designs can be made, where appropriate, to make the technology successful in treating halogenated compounds.

Subsurface contamination by VOCs potentially exists in four phases:

· Gaseous phase: Contaminants present as vapors in unsaturated zone.

· Solid phase: Contaminants in liquid form adsorbed on soil particles in both saturated and unsaturated zones.

- Aqueous phase: Contaminants dissolved into pore water according to their solubility in both saturated and unsaturated zones.

- Immiscible phase: Contaminants present as non-aqueous phase liquids (NAPLs) primarily in unsaturated zone.

One or more of the fluid phases (gaseous, liquid, aqueous, or immiscible) may occupy the pore spaces in the unsaturated zone. Residual bulk liquid may be retained by capillary attraction in the porous media (i.e., NAPLs are no longer a continuous phase but are present as isolated residual globules).

Residual saturation of bulk liquid may occur through a number of mechanisms. Volatilization from residual saturation or bulk liquid into the unsaturated pore spaces produces a vapor plume. Lateral migration of this vapor plume is independent of groundwater movement and may occur as a result of both advection and diffusion. Advection is the process by which the vapor plume contaminants are transported by the movement of air and may result from gas pressure or gas density gradients. Diffusion is the movement of contaminants from areas of high vapor concentrations to areas of lower vapor concentrations. Volatilization from contaminated groundwater also may produce a vapor plume of compounds with high vapor pressures and high aqueous solubilities.

Dissolution of contaminants from residual saturation or bulk liquid into water may occur in either the unsaturated or saturated portions of the subsurface with the contamination then moving with the water. Even low-solubility organics may be present at low concentrations dissolved in water.

Insoluble organic contaminants may be present as NAPLs. Dense NAPLs (DNAPLs) have a specific gravity greater than 1 and will tend to sink to the bottom of surface waters and groundwater aquifers. Light NAPLs (LNAPLs) will float on top of surface water and groundwater. In addition, DNAPLs and LNAPLs may adhere to the soil through the capillary fringe and may be found on top of water in temporary or perched aquifers in the vadose zone.

✍ 2.3.2 Common Treatment Technologies for VOCs in Soil, Sediment, and Sludge

Soil vapor extraction (SVE), thermal desorption, and incineration are the presumptive remedies for Superfund sites with VOC-contaminated soil. Because a presumptive remedy is a technology that EPA believes, based upon its past experience, generally will be the most appropriate remedy for a specified type of site, the presumptive remedy approach will accelerate site-specific analysis of remedies by focusing the feasibility study efforts. These presumptive remedies can also be used at non-Superfund sites with VOC-contaminated soils.

SVE is the preferred presumptive remedy. SVE has been selected most frequently to address VOC contamination at Superfund sites, and performance data indicate that it effectively treats waste in place at a relatively low cost. In cases where SVE

will not work or where uncertainty exists regarding the ability to obtain required cleanup levels, thermal desorption may be the most appropriate response technology. In a limited number of situations, incineration may be most appropriate.

Another commonly used technology, bioventing, uses a similar approach to vapor extraction in terms of equipment type and layout but uses air injection rather than extraction and has a different objective: the intent is to use air movement to provide oxygen for aerobic degradation using either indigenous or introduced microorganisms. While some organic materials are usually brought to the surface for treatment with the exhaust air, additional degradation is encouraged in situ. This difference in approach renders less volatile materials (particularly fuel products such as diesel fuel) amenable to the process because volatilization into the soil air is not the primary removal process.

The AFCEE Bioventing Initiative currently encompasses 135 fuel sites at 50 military installations, including one Marine, one Army, and one Coast Guard facility. Approximately 50% of the current systems are full scale. As of July 1994, approximately 117 are installed and operating. The remainder are to be installed.

✍ 2.3.3 Common Treatment Technologies for VOCs in Groundwater, Surface Water, and Leachate

In addition to the general data requirements discussed in Subsection 2.2.2, it may be necessary to know other subsurface information to provide remediation of VOCs in the groundwater. Treatability studies to characterize the biodegradability may be needed for any biodegradation technologies. **Treatability studies** are usually necessary to ensure that the contaminated groundwater can be treated effectively at the design flow. A **subsurface geologic** characterization would be needed for any isolation or stabilization technologies. **Groundwater models** are also often needed to predict flow characteristics, changes in contaminant mixes and concentrations, and times to reach cleanup levels.

The most commonly used technologies to treat VOCs in groundwater, surface water, and leachate are air stripping and carbon adsorption. These are both ex situ technologies requiring groundwater extraction.

Air stripping involves the mass transfer of volatile contaminants from water to air. This process is typically conducted in a packed tower or an aeration tank. The generic packed tower air stripper includes a spray nozzle at the top of the tower to distribute contaminated water over the packing in the column, a fan to force air countercurrent to the water flow, and a sump at the bottom of the tower to collect decontaminated water. Auxiliary equipment that can be added to the basic air stripper includes a feed water heater (normally not incorporated within an operational facility because of the high cost) and an air heater to improve removal efficiencies, automated control systems with sump level switches and safety features such as differential pressure monitors, high sump level switches and explosion proof components, and discharge air treatment systems such as activated carbon units,

catalytic oxidizers, or thermal oxidizers. Packed tower air strippers are installed either as permanent installations on concrete pads, or as temporary installations on skids, or on trailers.

Liquid phase carbon adsorption is a full-scale technology in which groundwater is pumped through a series of vessels containing activated carbon to which dissolved contaminants adsorb. When the concentration of contaminants in the effluent from the bed exceeds a certain level, the carbon can be regenerated in place; removed and regenerated at an off-site facility; or removed and disposed of. Carbon used for explosives- or metals-contaminated groundwater must be removed and properly disposed of. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes.

✍ 2.3.4 Common Treatment Technologies for VOCs in Air Emissions/ Off-Gases

Three technologies that are most commonly used to treat VOCs in air emissions/off-gases are carbon adsorption, catalytic oxidation, and thermal oxidation.

Carbon adsorption is a remediation technology in which pollutants are removed from air by physical adsorption onto the carbon grain. Carbon is "activated" for this purpose by processing the carbon to create porous particles with a large internal surface area (300 to 2,500 square meters per gram of carbon) that attracts and adsorbs organic molecules as well as certain metal and other inorganic molecules.

Commercial grades of activated carbon are available for specific use in vapor-phase applications. The granular form of activated carbon is typically used in packed beds through which the contaminated air flows until the concentration of contaminants in the effluent from the carbon bed exceeds an acceptable level. Granular activated carbon systems typically consist of one or more vessels filled with carbon connected in series and/or parallel operating under atmospheric, negative, or positive pressure. The carbon can then be regenerated in place, regenerated at an off-site regeneration facility, or disposed of, depending upon economic considerations.

Catalytic oxidation is a relatively new alternative for the treatment of VOCs in air streams resulting from remedial operations. VOCs are thermally destroyed at temperatures typically ranging from 600 to 1,000 ?F by using a solid catalyst. First, the contaminated air is directly preheated (electrically or, more frequently, using natural gas or propane) to reach a temperature necessary to initiate the catalytic oxidation of the VOCs. Then the preheated VOC-laden air is passed through a bed of solid catalysts where the VOCs are rapidly oxidized.

In most cases, the process can be enhanced to reduce auxiliary fuel costs by using an air-to-air heat exchanger to transfer heat from the exhaust gases to the incoming contaminated air. Typically, about 50% of the heat of the exhaust gases is recovered. Depending on VOC concentrations, the recovered heat may be sufficient to sustain oxidation without additional fuel. Catalyst systems used to oxidize VOCs typically use metal oxides such as nickel oxide, copper oxide, manganese dioxide, or

chromium oxide. Noble metals such as platinum and palladium may also be used. However, in a majority of remedial applications, nonprecious metals (e.g., nickel, copper, or chromium) are used. Most commercially available catalysts are proprietary.

Thermal oxidation equipment is used for destroying contaminants in the exhaust gas from air strippers and SVE systems. Probably fewer than 100 oxidizers have been sold to treat air stripper effluents; most of these units are rated less than 600 scfm. Typically, the blower for the air stripper or the vacuum extraction system provides sufficient positive pressure and flow for thermal oxidizer operation.

Thermal oxidation units are typically single chamber, refractory-lined oxidizers equipped with a propane or natural gas burner and a stack. Lightweight ceramic blanket refractory is used because many of these units are mounted on skids or trailers. Thermal oxidizers are often equipped with heat exchangers where combustion gas is used to preheat the incoming contaminated gas. If gasoline is the contaminant, heat exchanger efficiencies are limited to 25 to 35% and preheat temperatures are maintained below 530 ?F to minimize the possibility of ignition occurring in the heat exchanger. Flame arrestors are always installed between the vapor source and the thermal oxidizer. Burner capacities in the combustion chamber range from 0.5 to 2 million Btus per hour. Operating temperatures range from 1,400 to 1,600 ?F, and gas residence times are typically 1 second or less.

✍ 2.4 SEMIVOLATILE ORGANIC COMPOUNDS (SVOCs)

Sites where SVOCs may be found include burn pits, chemical manufacturing plants and disposal areas, contaminated marine sediments, disposal wells and leach fields, electroplating/metal finishing shops, firefighting training areas, hangars/aircraft maintenance areas, landfills and burial pits, leaking collection and system sanitary lines, leaking storage tanks, radiologic/mixed waste disposal areas, oxidation ponds/lagoons, pesticide/herbicide mixing areas, solvent degreasing areas, surface impoundments, and vehicle maintenance areas and wood preserving sites. Potentially applicable remediation technologies are presented in Table 2-2. Typical SVOCs (excluding fuels and explosives, which are presented in Subsection 2.5) encountered at many sites include the following:

· Halogenated SVOCs

- Bis(2-chloroethoxy)ether
- 1,2-Bis(2-chloroethoxy) ethane
- Bis(2-chloroethoxy) methane
- Bis(2-chloroethoxy) phthalate
- Bis(2-chloroethyl)ether
- Bis(2-chloroisopropyl) ether
- 4-Bromophenyl phenyl ether
- 4-Chloroaniline
- p-Chloro-m-cresol
- 2-Chloronaphthalene
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene
- 3,3-Dichlorobenzidine
- 2,4-Dichlorophenol
- Hexachlorobenzene
- Hexachlorobutadiene
- Hexachlorocyclopentadiene
- Pentachlorophenol (PCP)
- Polychlorinated biphenyls (PCBs)
- Tetrachlorophenol

- 1,2,4-Trichlorobenzene

TABLE 2-2 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF SEMIVOLATILE ORGANIC COMPOUNDS

Technology (Text Section and Title)		Development Status	Use Rating	Applicability*	Technology Function*
SOIL, SEDIMENT, AND SLUDGE					
3.1	**IN SITU BIOLOGICAL TREATMENT**				
4.1	Biodegradation	Full	Wide	Better	Destruct
4.2	Bioventing	Full	Limited	Average	Destruct
3.2	**IN SITU PHYSICAL/CHEMICAL TREATMENT**				
4.5	Soil Flushing	Pilot	Limited	Average	Extract
4.6	Soil Vapor Extraction	Full	Limited	Below	Extract
4.7	Solidification/Stabilization	Full	Limited	Average	Immob.
3.3	**IN SITU THERMAL TREATMENT**				
4.8	Thermally Enhanced SVE	Full	Limited	Better	Extract
4.9	In Situ Vitrification	Pilot	Limited	Average	Ext./Destruct
3.4	**EX SITU BIOLOGICAL TREATMENT (ASSUMING EXCAVATION)**				
4.10	Composting	Full	Wide	Average	Destruct
4.11	Control. Solid Phase Bio. Treat.	Full	Wide	Average	Destruct
4.12	Landfarming	Full	Wide	Average	Destruct
4.13	Slurry Phase Bio. Treatment	Full	Limited	Average	Destruct
3.5	**EX SITU PHYSICAL/CHEMICAL TREATMENT (ASSUMING EXCAVATION)**				
4.14	Chemical Reduction/ Oxidation	Full	Limited	Average	Destruct
4.15	Dehalogenation (BCD)	Full	Limited	Better	Destruct
4.16	Dehalogenation (Glycolate)	Full	Limited	Better	Destruct
4.17	Soil Washing	Full	Limited	Better	Extract
4.18	Soil Vapor Extraction	Full	Limited	Below Average	Extract
4.19	Solidification/Stabilization	Full	Limited	Average	Dest./Immob.
4.20	Solvent Extraction	Full	Limited	Better	Extract
3.6	**EX SITU THERMAL TREATMENT (ASSUMING EXCAVATION)**				
4.21	High Temp. Thermal Desorption	Full	Limited	Better	Extract
4.23	Incineration	Full	Wide	Better	Destruct
4.24	Low Temp. Thermal Desorption	Full	Limited	Average	Extract
4.26	Pyrolysis	Pilot	Limited	Better	Destruct
4.27	Vitrification	Full	Limited	Average	Ext./Destruct
3.7	**OTHER TREATMENT**				
4.28	Excavation/Off-Site Disp.	NA	Wide	Average	Ext./Immob.
4.29	Natural Attenuation	NA	Limited	Better	Destruct
GROUNDWATER, SURFACE WATER, AND LEACHATE					
3.8	**IN SITU BIOLOGICAL TREATMENT**				
4.30	Co-Metabolic Treatment	Pilot	Limited	Better	Destruct
4.31	Nitrate Enhancement	Pilot	Limited	Better	Destruct
4.32	Oxygen Enhance. w/Air Sparg.	Full	Limited	Better	Destruct
4.33	Oxygen Enhance. w/H_2O_2	Full	Limited	Better	Destruct
3.9	**IN SITU PHYSICAL/CHEMICAL TREATMENT**				
4.37	Free Product Recovery	Full	Limited	Better	Extract
4.38	Hot Water or Steam Flush/Strip	Pilot	Limited	Better	Extract
4.40	Passive Treatment Walls	Pilot	Limited	Better	Extract
4.41	Slurry Walls	Full	Limited	Average	Immob.
4.42	Vacuum Vapor Extraction	Pilot	Limited	Average	Extract
3.10	**EX SITU BIOLOGICAL TREATMENT (ASSUMING PUMPING)**				
4.43	Bioreactors	Full	Average	Better	Destruct
3.11	**EX SITU PHYSICAL/CHEMICAL TREATMENT (ASSUMING PUMPING)**				
4.44	Air Stripping	Full	Limited	Average	Extract

TABLE 2-2 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF SEMIVOLATILE ORGANIC COMPOUNDS

	4.47 Liquid Phase Carbon Adsorp.	Full	Wide	Better	Extract
	4.49 UV Oxidation	Full	Wide	Better	Destruct
3.12	**OTHER TREATMENT**				
	4.50 Natural Attenuation	NA	Limited	Better	Destruct

*The following rankings are discussed in Table 3-1 and Figure 3-1.

- 2-Chlorophenol
- 4-Chlorophenyl phenylether
- 1,2-Dichlorobenzene
- 2,4,5-Trichlorophenol
- 2,4,6-Trichlorophenol

· Nonhalogenated SVOCs

- Benzidine
- Benzoic Acid
- Benzyl alcohol
- Bis(2-ethylhexyl)phthalate
- Butyl benzyl phthalate
- Dibenzofuran
- Di-n-butyl phthalate
- Di-n-octyl phthalate
- Diethyl phthalate
- Dimethyl phthalate
- 4,6-Dinitro-2-methylphenol
- 2,4-Dinitrophenol
- 1,2-Diphenylhydrazine
- Isophorone
- 2-Nitroaniline
- 3-Nitroaniline
- 4-Nitroaniline
- 2-Nitrophenol
- 4-Nitrophenol
- n-Nitrosodimethylamine
- n-Nitrosodiphenylamine
- n-Nitrosodi-n-propylamine
- Phenyl naphthalene

· Polynuclear Aromatic Hydrocarbons (PAHs)

- Acenaphthene
- Acenaphthylene
- Anthracene
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Chrysene
- Fluoranthene
- Fluorene
- Indeno(1,2,3-cd)pyrene
- 2-Methylnaphthalene
- Naphthalene
- Phenanthrene
- Pyrene

· 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
- Ethyl parathion
- Heptachlor
- Heptachlor epoxide
- Malathion
- Methylparathion
- Parathion
- Toxaphene

✍ 2.4.1 Properties and Behavior of SVOCs

As previously discussed for VOCs, an important consideration when evaluating a remedy is whether the compound is halogenated or nonhalogenated. A halogenated

compound is one onto which a halogen (e.g., fluorine, chlorine, bromine, or iodine) has been attached. Typical halogenated and nonhalogenated SVOCs are listed at the beginning of Subsection 2.4. The nature of the halogen bond and the halogen itself can significantly affect performance of a technology or require more extensive treatment than for nonhalogenated compounds.

As an example, consider bioremediation. Generally, halogenated compounds are less amenable to this form of treatment than nonhalogenated compounds. In addition, the more halogenated the compound (i.e., the more halogens attached to it), the more refractive it is toward biodegradation. As another example, incineration of halogenated compounds requires specific off-gas and scrubber water treatment for the halogen in addition to the normal controls that are implemented for nonhalogenated compounds.

Therefore, the vendor of the technology being evaluated must be informed whether the compounds to be treated are halogenated or nonhalogenated. In most instances, the vendor needs to know the specific compounds involved so that modifications to technology designs can be made, where appropriate, to make the technology successful in treating halogenated compounds.

Subsurface contamination by SVOCs potentially exists in four phases:

- Gaseous phase: contaminants present as vapors in saturated zone.
- Solid phase: contaminants adsorbed or partitioned onto the soil or aquifer material in both saturated and unsaturated zones.
- Aqueous phase: contaminants dissolved into pore water according to their solubility in both saturated and unsaturated zones.
- Immiscible phase: contaminants present as NAPLs primarily in saturated zone.

One or more of the three fluid phases (gaseous, aqueous, or immiscible) may occupy the pore spaces in the unsaturated zone. Residual bulk liquid may be retained by capillary attraction in the porous media (i.e., NAPLs are no longer a continuous phase but are present as isolated residual globules).

Contaminant flow may occur through a number of mechanisms. Volatilization from residual saturation or bulk liquid into the unsaturated pore spaces produces a vapor plume. While the degree of volatilization from SVOCs is much less than for VOCs, this process still occurs.

Dissolution of contaminants from residual saturation or bulk liquid into water may occur in either the unsaturated or saturated portions of the subsurface with the contamination then moving with the water. Even low-solubility organics may be present at low concentrations dissolved in water.

Insoluble or low solubility organic contaminants may be present as NAPLs. DNAPLs will tend to sink to the bottom of surface waters and groundwater aquifers. LNAPLs will float on top of surface water and groundwater. In addition, LNAPLs may adhere to the soil through the capillary fringe and may be found on top of water in temporary or perched aquifers in the vadose zone.

Properties and behavior of specific SVOC contaminants and contaminant groups are discussed below:

- **PAHs:** PAHs are generally biodegradable in soil systems. Lower molecular weight PAHs are transformed much more quickly than higher molecular weight PAHs. The less degradable, higher molecular weight compounds have been classified as carcinogenic PAHs (cPAHs). Therefore, the least degradable fraction of PAH contaminants in soils is generally subject to the most stringent cleanup standards. This presents some difficulty in achieving cleanup goals with bioremediation systems.

  Lower molecular weight PAH components are more water soluble than higher molecular weight PAHs. Readily mobilized compounds, such as naphthalene, phenanthrene, and anthracene, are slightly water-soluble. Persistent PAHs, such as chrysene and benzo(a)pyrene, present even lower water solubilities. Pyrene and fluoranthene are exceptions because these compounds are more soluble than anthracene, but are not appreciably metabolized by soil microorganisms. Other factors affect PAH persistence such as insufficient bacterial membrane permeability, lack of enzyme specificity, and insufficient aerobic conditions. PAHs may undergo significant interactions with soil organic matter.

  Intermediate PAH degradation products (metabolites) in soil treatment systems may also display toxicity. Complete mineralization of PAHs is slow; intermediates may remain for substantial periods of time.

- **PCBs:** PCBs encompass a class of chlorinated compounds that includes up to 209 variations or congeners with different physical and chemical characteristics. PCBs were commonly used as mixtures called aroclors. The most common aroclors are Aroclor-1254, Aroclor-1260, and Aroclor-1242. PCBs alone are not usually very mobile in subsurface soils or water; however, they are typically found in oils associated with electrical transformers or gas pipelines or sorbed to soil particles, which may transport the PCBs by wind or water erosion.

- **Pentachlorophenol (PCP):** PCP is a contaminant found at many wood-preserving sites. PCP does not decompose when heated to its boiling point for extended periods of time. Pure PCP is chemically rather inert. The chlorinated ring structure tends to increase stability, but the polar hydroxyl group facilitates biological degradation. All monovalent alkali metal salts of PCP are very soluble in water. The protonated (phenolic) form is less

soluble, but this degree of solubility is still significant from an environmental standpoint. PCP can also volatilize from soils. It is denser than water, but the commonly used solution contains PCP and petroleum solvents in a mixture less dense than water. Therefore, technical grade PCP floats on the top of groundwater as a LNAPL.

- **Pesticides:** The term pesticide is applied to literally thousands of different, specific chemical-end products. Pesticides include insecticides, fungicides, herbicides, acaricides, nematodicides, and rodenticides. There are several commonly used classification criteria that can be used to group pesticides for purposes of discussion. Conventional methods of classifying pesticides base categorization on the applicability of a substance or product to the type of pest control desired. (For example, DDT is used typically as an insecticide.) The RCRA hazardous waste classification system is based on waste characterization and sources. Neither of these classification formats is suitable for use in this document because they have no bearing on applicable pesticide treatment technologies.

✍ 2.4.2 Common Treatment Technologies for SVOCs in Soil, Sediment, and Sludge

Common treatment technologies for SVOCs in soil, sediment, and sludge include biodegradation, incineration, and excavation with off-site disposal.

All types of biodegradation, both in situ or ex situ, can be considered to remediate soils: in situ bioremediation, bioventing, composting, controlled solid phase, or landfarming. Slurry phase biological treatment is also applicable but is less widely used. Treatability studies should be conducted to evaluate design parameters, such as degradation rates, supplemental organism addition, cleanup levels achievable, degradation intermediates, and nutrient/oxygen addition.

Biodegradation uses a process in which indigenous or inoculated microorganisms (e.g., fungi, bacteria, and other microbes) degrade (i.e., metabolize) organic contaminants found in soil and/or groundwater. In the presence of sufficient oxygen (aerobic conditions), microorganisms will ultimately convert many organic contaminants to carbon dioxide, water, and microbial cell mass. In the absence of oxygen (anaerobic conditions), the contaminants will be ultimately metabolized to methane and carbon dioxide. Sometimes contaminants may not be completely degraded, but only transformed to intermediate products that may be less, equally, or more hazardous than the original contaminant.

The in situ bioremediation of soil typically involves the percolation or injection of groundwater or uncontaminated water mixed with nutrients. Ex situ bioremediation typically uses tilling or continuously mixed slurries to apply oxygen and nutrients, and is performed in a prepared bed (liners and aeration) or reactor.

Incineration uses high temperatures, 870 to 1,200 ?C (1,400 to 2,200 ?F), to volatilize and combust (in the presence of oxygen) organic constituents in hazardous

wastes. The destruction and removal efficiency (DRE) for properly operated incinerators exceeds the 99.99% requirement for hazardous waste and can be operated to meet the 99.9999% requirement for PCBs and dioxins.

Distinct incinerator designs available for solids are rotary kiln, fluidized bed, and infrared units. All three types have been used successfully at full scale.

Excavation and removal of contaminated soil (with or without stabilization) to a landfill have been performed extensively at many sites. Landfilling of hazardous materials, especially hazardous wastes, is becoming increasingly difficult and expensive as a result of growing regulatory control, and may be cost-prohibitive for sites with large volumes, greater depths, or complex hydrogeologic environments. Determining the feasibility of off-site disposal requires knowledge of land disposal restrictions and other regulations developed by state governments.

✍ 2.4.3 Common Treatment Technologies for SVOCs in Groundwater, Surface Water, and Leachate

In addition to the general data requirements discussed in Subsection 2.2.2, it may be necessary to know other subsurface information to remediate semivolatile organics in water. **Treatability studies** may be required to determine the contaminant biodegradability for any biodegradation technologies. Treatability studies are also necessary to ensure that the contaminated groundwater can be treated effectively at the design flow. A **subsurface geologic** characterization would be particularly useful to any isolation or stabilization technologies. **Groundwater models** are also often needed to predict flow characteristics, changes in contaminant mixes and concentrations, capture zones, and times to reach clean up levels.

The most commonly used ex situ treatment technologies for SVOCs in groundwater and surface water include carbon adsorption and UV oxidation. In situ treatment technologies are not widely used. Groundwater and surface water concentrations not sufficiently high to support biological processes, however, for leachate biological process may be applicable.

Liquid phase carbon adsorption is a full-scale technology in which groundwater is pumped through a series of vessels containing activated carbon to which dissolved contaminants are adsorbed. When the concentration of contaminants in the effluent from the bed exceeds a certain level, the carbon can be regenerated in place; removed and regenerated at an off-site facility; or removed and disposed of. Carbon used for explosives- or metals-contaminated groundwater must be removed and properly disposed of. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes.

UV oxidation is a destruction process that oxidizes organic and explosive constituents in wastewaters by the addition of strong oxidizers and irradiation with intense UV light. The oxidation reactions are catalyzed by UV light, while ozone (O_3) and/or hydrogen peroxide (H_2O_2) are commonly used as oxidizing agents. The final products of oxidation are carbon dioxide, water, and salts. The main advantage of UV oxidation is that organic contaminants can be converted to

relatively harmless carbon dioxide and water by hydroxyl radicals generated during the process. UV oxidation processes can be configured in batch or continuous flow modes. Catalyst addition may enhance the performance of the system.

✍ 2.5 FUELS

Sites where fuel contaminants may be found include aircraft areas, burn pits, chemical disposal areas, contaminated marine sediments, disposal wells and leach fields, firefighting training areas, hangars/aircraft maintenance areas, landfills and burial pits, leaking storage tanks, solvent degreasing areas, surface impoundments, and vehicle maintenance areas. Potentially applicable remediation technologies are presented in Table 2-3. Typical fuel contaminants encountered at many sites include the following:

- Acenaphthene
- Anthracene
- Benz(a)anthracene
- Benzene
  - Benzo(b)fluoranthene
  - Benzo(k)fluoranthene
  - Benzo(g,h,i)perylene
  - Benzo(a)pyrene
  - Chrysene
  - Cis-2-butene
  - Creosols
- Cyclohexane
- Cyclopentane
- Dibenzo(a,h)anthracene
- 2,3-Dimethylbutane
- 3,3-Dimethyl-1-butene
- Dimethylethylbenzene
- 2,2-Dimethylheptane
- 2,2-Dimethylhexane
- 2,2-Dimethylpentane
- 2,3-Dimethylpentane
- 2,4-Dimethylphenol
- Ethylbenzene
- 3-Ethylpentane
- Fluoranthene
- Fluorene
- Ideno(1,2,3-c,d)pyrene
- Isobutane
- Isopentane
- 2-Methyl-1,3-butadiene
- 3-Methyl-1,2-butadiene
- 2-Methyl-butene
- 2-Methyl-2-butene
- 3-Methyl-1-butene
- Methylcyclohexane

- Methylcyclopentane
- 2-Methylheptane
- 3-Methylheptane
- 3-Methylhexane
- Methylnaphthalene
- 2-Methylnaphthalene
- 2-Methylpentane
- 3-Methylpentane
- 3-Methyl-1-pentene
- 2-Methylphenol
- 4-Methylphenol
- Methylpropylbenzene
- m-Xylene
- Naphthalene
- n-Butane
- n-Decane
- n-Dodecane
- n-Heptane
- n-Hexane
- n-Hexylbenzene
- n-Nonane
- n-Nonane
- n-Octane
- n-Pentane
- n-Propylbenzene
- n-Undecane
- o-Xylene
- 1-Pentene
- Phenanthrene
- Phenol
- Propane
- p-Xylene
- Pyrene
- Pyridine
- 1,2,3,4-Tetramethylbenzene

TABLE 2-3 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF FUELS

Technology (Text Section and Title)		Development Status	Use Rating	Applicability*	Technology Function*
SOIL, SEDIMENT, AND SLUDGE					
3.1	**IN SITU BIOLOGICAL TREATMENT**				
	4.1 Biodegradation	Full	Wide	Better	Destruct
	4.2 Bioventing	Full	Wide	Better	Destruct
3.2	**IN SITU PHYSICAL/CHEMICAL TREATMENT**				
	4.5 Soil Flushing	Pilot	Limited	Average	Extract
	4.6 Soil Vapor Extraction (SVE)	Full	Wide	Better	Extract
3.3	**IN SITU THERMAL TREATMENT**				
	4.8 Thermally Enhanced SVE	Full	Limited	Better	Extract

TABLE 2-3 TREATMENT TECHNOLOGIES SCREENING MATRIX:
TREATMENT OF FUELS

	4.9 In Situ Vitrification	Pilot	Limited	Below Average	Immob./Dest.
3.4	**EX SITU BIOLOGICAL TREATMENT (ASSUMING EXCAVATION)**				
	4.10 Composting	Full	Wide	Better	Destruct
	4.11 Control. Solid Phase Bio.	Full	Wide	Better	Destruct
	4.12 Landfarming	Full	Wide	Better	Destruct
	4.13 Slurry Phase Bio. Treatment	Full	Limited	Better	Destruct
3.5	**EX SITU PHYSICAL/CHEMICAL TREATMENT (ASSUMING EXCAVATION)**				
	4.14 Chemical	Full	Limited	Below Average	Destruct
	4.17 Soil Washing	Full	Limited	Better	Extract
	4.18 Soil Vapor Extraction	Full	Limited	Average	Extract
	4.20 Solvent Extraction	Full	Limited	Average	Extract
3.6	**EX SITU THERMAL TREATMENT (ASSUMING EXCAVATION)**				
	4.21 High Temp. Thermal	Full	Limited	Average	Extract
	4.23 Incineration	Full	Limited	Better	Destruct
	4.24 Low Temp. Thermal	Full	Wide	Better	Extract
	4.26 Pyrolysis	Pilot	Limited	Average	Destruct
	4.27 Vitrification	Full	Limited	Average	Ext./Destruct
3.7	**OTHER TREATMENT**				
	4.28 Excavation/Off-Site Disp.	NA	Wide	Average	Ext./Immob.
	4.29 Natural Attenuation	NA	Limited	Better	Destruct
3.8	**IN SITU BIOLOGICAL TREATMENT**				
	4.30 Co-Metabolic Treatment	Pilot	Limited	Average	Destruct
	4.31 Nitrate Enhancement	Pilot	Limited	Better	Destruct
	4.32 Oxygen Enhance. w/Air	Full	Limited	Better	Destruct
	4.33 Oxygen Enhance. w/H_2O_2	Full	Limited	Better	Destruct
3.9	**IN SITU PHYSICAL/CHEMICAL TREATMENT**				
	4.34 Air Sparging	Full	Limited	Better	Extract
	4.36 Dual Phase Extraction	Full	Limited	Better	Extract
	4.37 Free Product Recovery	Full	Wide	Better	Extract
	4.38 Hot Water or Steam	Pilot	Limited	Better	Extract
	4.40 Passive Treatment Walls	Pilot	Limited	Average	Destruct
	4.41 Slurry Walls	Full	Limited	Average	Immob.
	4.42 Vacuum Vapor Extraction	Pilot	Limited	Better	Extract
3.10	**EX SITU BIOLOGICAL TREATMENT (ASSUMING PUMPING)**				
	4.43 Bioreactors	Full	Limited	Better	Destruct
3.11	**EX SITU PHYSICAL/CHEMICAL TREATMENT (ASSUMING PUMPING)**				
	4.44 Air Stripping	Full	Wide	Average	Extract
	4.47 Liquid Phase Carbon	Full	Wide	Average	Extract
	4.49 UV Oxidation	Full	Limited	Better	Destruct
3.12	**OTHER TREATMENT**				
	4.50 Natural Attenuation	NA	Limited	Better	Destruct

*The following rankings are discussed in Table 3-1 and Figure 3-1.

- 1,2,4,5-Tetramethylbenzene
- Toluene
- 1,2,4-Trimethylbenzene
- 1,3,5-Trimethylbenzene
- 1,2,4-Trimethyl-5-ethylbenzene
- 2,2,4-Trimethylheptane
- 2,3,4-Trimethylheptane
- 3,3,5-Trimethylheptane
- 2,4,4-Trimethylhexane
- 2,3,4-Trimethylhexane
- 2,2,4-Trimethylpentane
- 2,3,4-Trimethylpentane
- Trans-2-butene
- Trans-2-pentene

✍ 2.5.1 Properties and Behavior of Fuels

Information presented for VOCs (Subsection 2.3.1) and SVOCs (Subsection 2.4.1) may also be appropriate for many of the fuel contaminants presented in this subsection. As previously discussed for VOCs and SVOCs, an important consideration when evaluating a remedy is whether the compound is halogenated or nonhalogenated. Fuel contaminants are nonhalogenated. A halogenated compound is one onto which a halogen (e.g., fluorine, chlorine, bromine, or iodine) has been attached. The nature of the halogen bond and the halogen itself can significantly affect performance of a technology or require more extensive treatment than for nonhalogenated compounds.

As an example, consider bioremediation. Generally, halogenated compounds are less amenable to this form of treatment than nonhalogenated compounds. In addition, the more halogenated the compound (i.e., the more halogens attached to it), the more refractive it is toward biodegradation. As another example, incineration of halogenated compounds requires specific off-gas and scrubber water treatment for the halogen in addition to the normal controls that are implemented for nonhalogenated compounds.

Therefore, the vendor of the technology being evaluated must be informed whether the compounds to be treated are halogenated or nonhalogenated. In most instances, the vendor needs to know the specific compounds involved so that modifications to technology designs can be made, where appropriate, to make the technology successful in treating halogenated compounds.

Contamination by fuel contaminants in the unsaturated zone exists in four phases: vapor in the pore spaces; sorbed to subsurface solids; dissolved in water; or as NAPL. The nature and extent of transport are determined by the interactions among contaminant transport properties (e.g., density, vapor pressure, viscosity, and hydrophobicity) and the subsurface environment (e.g., geology, aquifer mineralogy, and groundwater hydrology). Most fuel-derived contaminants are less dense than water and can be detected as floating pools (LNAPLs) on the water table.

Typically, after a spill occurs, LNAPLs migrate vertically in the subsurface until residual saturation depletes the liquid or until the capillary fringe above the water table is reached. Some spreading of the bulk liquid occurs until pressure from the infiltrating liquid develops sufficiently to penetrate to the water table. The pressure of the infiltrating liquid pushes the spill below the surface of the water table. Bulk liquids less dense than water spread laterally and float on the surface of the water table, forming a mound that becomes compressed into a spreading lens.

As the plume of dissolved constituents moves away from the floating bulk liquid, interactions with the soil particles affect dissolved concentrations. Compounds more attracted to the aquifer material move at a slower rate than the groundwater and are found closer to the source; compounds less attracted to the soil particles move most rapidly and are found in the leading edge of a contaminant plume.

More volatile LNAPL compounds readily partition into the air phase. A soil gas sample collected from an area contaminated by vapor-phase transport typically contains relatively greater concentrations of the more volatile compounds than one contaminated by groundwater transport. Vapor-phase transport can be followed by subsequent dissolution in groundwater. Alternatively, aqueous-phase contaminants with high Henry's law constants can be expected to volatilize into the pore spaces.

For compounds with vapor densities greater than air, density-driven flow of the vapor plume may occur as a result of gas density gradients. Toluene, ethylbenzene, xylenes and naphthalene are less dense than water and unlikely to move by density-driven flow. However, they may be capable of diffusive transport, causing vapor plumes to move away from residual saturation in the unsaturated zone. Residual saturation is the portion of the liquid contaminant that remains in the pore spaces as a result of capillary attraction after the NAPL moves through the soil. Volatilization from contaminated groundwater also may produce a vapor plume of compounds with high vapor pressures and high aqueous solubilities. Dissolution of contaminants from residual saturation or bulk liquid into water may occur in either the unsaturated or saturated portions of the subsurface with the contamination then moving with the water. Because the solubility of fuels is relatively low, contaminant dissolution from NAPL under laminar flow conditions typical of aquifers is mass-transfer limited, requiring decades for dissolution and producing a dilute wastestream of massive volume.

✍ 2.5.2 Common Treatment Technologies for Fuels in Soil, Sediment, and Sludge

Common treatment technologies for fuels in soil, sediment, and sludge include biodegradation, incineration, SVE, and low temperature thermal desorption. Incineration is typically used when chlorinated SVOCs are also present with fuel, and not specified for fuel-only contaminated soil, sediment, or sludge.

All types of **biodegradation**, both in situ or ex situ, can be used to remediate soils: in situ biodegradation, bioventing, composting, controlled solid phase, or landfarming. Slurry-phase biological treatment is also applicable but is less widely used. Biodegradation uses indigenous or inoculated microorganisms (e.g., fungi, bacteria, and other microbes) to degrade (i.e., metabolize) organic contaminants found in soil and/or groundwater. In the presence of sufficient oxygen (aerobic conditions), microorganisms will ultimately convert many organic contaminants to carbon dioxide, water, and microbial cell mass. In the absence of oxygen (anaerobic conditions), the contaminants will be ultimately metabolized to methane. Sometimes contaminants may not be completely degraded, but only transformed to intermediate products that may be less, equally, or more hazardous than the original contaminant.

The in situ bioremediation of soil typically involves the percolation or injection of groundwater or uncontaminated water mixed with nutrients and saturated with dissolved oxygen. Ex situ bioremediation typically uses tilling or continuously mixed slurries to apply oxygen and nutrients, and is performed in a prepared bed (liners and aeration) or reactor. Bioventing is an in situ technique that uses air injection to aerate the soil and enhance biodegradation. The AFCEE Bioventing Initiative currently encompasses 135 sites at 50 military installations, including one Marine, one Army, and one Coast Guard facility. Approximately 50% of the current systems are full-scale. As of July 1994, approximately 117 are installed and operating. The remainder are to be installed.

Incineration uses high temperatures, 870 to 1,200 ?C (1,400 to 2,200 ?F), to volatilize and combust (in the presence of oxygen) organic constituents in hazardous wastes. The destruction and removal efficiency (DRE) for properly operated incinerators exceeds the 99.99% requirement for hazardous waste and can be operated to meet the 99.9999% requirement for PCBs and dioxins. Distinct incinerator designs are rotary kiln, liquid injection, fluidized bed, and infrared units. All types have been used successfully at full scale.

Soil vapor extraction (SVE) is an in situ unsaturated (vadose) zone soil remediation technology in which a vacuum is applied to the soil to induce the controlled flow of air and remove volatile and some semivolatile contaminants from the soil. The gas leaving the soil may be treated to recover or destroy the contaminants, depending on local and state air discharge regulations. Explosion-proof equipment should be used for fuels. Vertical extraction vents are typically used at depths of 1.5 meters (5 feet) or greater and have been successfully applied as deep as 91 meters (300 feet). Horizontal extraction vents (installed in trenches or horizontal borings) can be used as warranted by contaminant zone geometry, drill rig access, or other site-specific factors.

Groundwater extraction pumps may be used to reduce groundwater upwelling induced by the vacuum or to increase the depth of the vadose zone. Air injection may be effective for facilitating extraction of deep contamination, contamination in low permeability soils, and contamination in the saturated zone (see Treatment Technology Profile 4.34, Air Sparging).

Low temperature thermal desorption (LTTD) systems are physical separation processes and are not designed to destroy organics. Wastes are heated to between 90 and 315 ?C (200 to 600 ?F) to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system. Groundwater treatment concentrates the collected contaminants (e.g., carbon adsorption or condensation). The bed temperatures and residence times designed into these systems will volatilize selected contaminants but will typically not oxidize them. LTTD is a full-scale technology that has been proven successful for remediating petroleum hydrocarbon contamination in all types of soil. Decontaminated soil retains its physical properties and ability to support biological activity.

✍ 2.5.3 Water and Treatment Technologies for Fuels in Groundwater, Surface

In addition to the general data requirements discussed in Subsection 2.2.2, it may be necessary to know other subsurface information to remediate fuels in groundwater. Treatability testing to characterize contaminant biodegradability and **nutrient content** may be needed for any biodegradation technologies. A **subsurface geologic** characterization would be particularly important to characterize the migration of NAPLs. **Recovery tests** are usually necessary to design a product/groundwater pumping scheme that will ensure that the nonaqueous fuel layer can be recovered and that contaminated groundwater can be treated effectively at the design flow. **Groundwater models** are also often needed to predict flow characteristics, changes in contaminant mixes and concentrations, capture zones, and times to reach cleanup levels.

Technologies most commonly used to treat fuels in groundwater include air stripping, carbon adsorption, and free product recovery. These are all ex situ treatment technologies requiring groundwater extraction.

Air stripping involves the mass transfer of volatile contaminants from water to air. For groundwater remediation, this process is typically conducted in a packed tower or an aeration tank. The generic packed tower air stripper includes a spray nozzle at the top of the tower to distribute contaminated water over the packing in the column, a fan to force air countercurrent to the water flow, and a sump at the bottom of the tower to collect decontaminated water. Auxiliary equipment that can be added to the basic air stripper includes automated control systems with sump level switches and safety features such as differential pressure monitors, high sump level switches and explosion proof components, and discharge air treatment systems such as activated carbon units, catalytic oxidizers, or thermal oxidizers. Packed tower air strippers are installed either as permanent installations on concrete pads, on a skid, or on a trailer.

Liquid phase carbon adsorption is a full-scale technology in which groundwater is pumped through a series of vessels containing activated carbon to which dissolved contaminants are adsorbed. When the concentration of contaminants in the effluent from the bed exceeds a certain level, the carbon can be regenerated in place; removed and regenerated at an off-site facility; or removed and disposed of. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes.

For **free product recovery,** undissolved liquid-phase organics are removed from subsurface formations, either by active methods (e.g., pumping) or a passive collection system. This process is used primarily in cases where a fuel hydrocarbon lens is floating on the water table. The free product is generally drawn up to the surface by a pumping system. Following recovery, it can be disposed of, re-used directly in an operation not requiring high-purity materials, or purified prior to re-use. Systems may be designed to recover only product, mixed product and water, or separate streams of product and water (i.e., dual pump or dual well systems). Free product recovery is a full-scale technology.

✍ 2.6 INORGANICS

Sites where inorganic contaminants may be found include artillery and small arms impact areas, battery disposal area, burn pits, chemical disposal areas, contaminated marine sediments, disposal wells and leach fields, electroplating/metal finishing shops, firefighting training areas, landfills and burial pits, leaking collection and system sanitary lines, leaking storage tanks, radioactive and mixed waste disposal areas, oxidation ponds/lagoons, paint stripping and spray booth areas, sand blasting areas, surface impoundments, and vehicle maintenance areas. Potentially applicable remediation technologies are presented in Table 2-4. Typical inorganic contaminants encountered at many sites include the following:

· Metals

- Aluminum
- Antimony
- Arsenic*
- Barium
- Beryllium
- Bismuth
- Boron
- Cadmium
- Calcium
- Chromium
- Cobalt
- Copper
- Iron
- Lead
- Magnesium
- Manganese
- Mercury
- Metallic cyanides
- Nickel
- Potassium
- Selenium
- Silver
- Sodium
- Thallium
- Tin
- Titanium
- Vanadium
- Zinc

· Radionuclides

- Americium-241
- Cesium-134, -137
- Cobalt-60
- Europium-152, -154, -155
- Plutonium-238, -239
- Radium-224, -226
- Strontium-90
- Technetium-99
- Thorium-228, -230, -232
- Uranium-234, -235, -2382

· Other inorganic contaminants

- Asbestos
- Cyanide
- Fluorine

* Although arsenic is not a true metal, it is included here because it is classified as one of the eight RCRA metals.

TABLE 2-4 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF INORGANICS

NOTE: Specific site and contaminant characteristics may limit the applicability and effectiveness of any of the technologies and treatments listed below. This matrix is optimistic in nature and should always be used in conjunction with the *referenced text sections*, which contain additional information that can be useful in identifying potentially applicable technologies.

Technology (Text Section and Title)		Development Scale	Use Rating	Applicability*	Technology Function*
SOIL, SEDIMENT, AND SLUDGE					
3.2	**IN SITU PHYSICAL/CHEMICAL TREATMENT**				
	4.7 Solidification/Stabilization	Full	Limited	Better	Immob.
	4.5 Soil Flushing	Pilot	Limited	Better	Extract
3.3	**IN SITU THERMAL TREATMENT**				
	4.9 Vitrification	Pilot	Limited	Better	Immob.
3.5	**EX SITU PHYSICAL/CHEMICAL TREATMENT (ASSUMING EXCAVATION)**				
	4.14 Chemical Reduction/Oxidation	Full	Limited	Better	Extract
	4.17 Soil Washing	Full	Limited	Better	Extract
	4.19 Solidification/Stabilization	Full	Wide	Better	Immob.
3.6	**EX SITU THERMAL TREATMENT (ASSUMING EXCAVATION)**				
	4.27 Vitrification	Full	Limited	Better	Immob.
3.7	**OTHER TREATMENT**				
	4.28 Excavation/Off-Site Disp.	NA	Wide	Average	Extract/Immob.
GROUNDWATER, SURFACE WATER, AND LEACHATE					
3.9	**IN SITU PHYSICAL/CHEMICAL TREATMENT**				
	4.40 Passive Treatment Walls	Pilot	Limited	Better	Extract
	4.41 Slurry Walls	Full	Limited	Average	Immob.
	4.42 Vacuum Vapor Extraction	Pilot	Limited	Average	Extract
3.10	**EX SITU PHYSICAL/CHEMICAL TREATMENT (ASSUMING PUMPING)**				
	4.45 Filtration	Full	Wide	Better	Extract
	4.46 Ion Exchange	Full	Wide	Better	Extract
	4.48 Precipitation	Full	Wide	Better	Extract

*The following rankings are discussed in Table 3-1 and Figure 3-1.

✍ 2.6.1 Properties and Behavior of Inorganics

Often, specific technologies may be ruled out, or the list of potential technologies may be immediately narrowed, on the basis of the presence or absence of one or more of the chemical groups. The relative amounts of each may tend to favor certain technologies. Metals may be found sometimes in the elemental form, but more often they are found as salts mixed in the soil. At the present time, treatment options for radioactive materials are probably limited to volume reduction/concentration and immobilization. Asbestos fibers require special care to prevent their escape during handling and disposal; permanent containment must be provided. Properties and behavior of specific inorganics and inorganic contaminant groups are discussed below.

2.6.1.1 Metals

Unlike the hazardous organic constituents, metals cannot be degraded or readily detoxified. The presence of metals among wastes can pose a long-term environmental hazard. The fate of the metal depends on its physical and chemical properties, the associated waste matrix, and the soil. Significant downward transportation of metals from the soil surface occurs when the metal retention capacity of the soil is overloaded, or when metals are solubilized (e.g., by low pH). As the concentration of metals exceeds the ability of the soil to retain them, the metals will travel downward with the leaching waters. Surface transport through dust and erosion of soils are common transport mechanisms. The extent of vertical contamination intimately relates to the soil solution and surface chemistry.

Properties and behavior of specific metals are discussed below:

- **Arsenic:** Arsenic (As) exists in the soil environment as arsenate, As(V), or as arsenite, As(III). Both are toxic; however, arsenite is the more toxic form, and arsenate is the most common form. (Note: Arsenic is not a true metal; however, it is included here as it is one of the eight RCRA metals.)

  The behavior of arsenate in soil seems analogous to that of phosphate because of their chemical similarity. Like phosphate, arsenate is fixed to soil, and thus is relatively immobile. Iron (Fe), aluminum (Al), and calcium (Ca) influence this fixation by forming insoluble complexes with arsenate. The presence of iron in soil is most effective in controlling arsenate's mobility. Arsenite compounds are 4 to 10 times more soluble than arsenate compounds.

  The adsorption of arsenite is also strongly pH-dependent. One study found increased adsorption of As(III) by two clays over the pH range of 3 to 9 while another study found the maximum adsorption of As(III) by iron oxide occurred at pH 7.

  Under anaerobic conditions, arsenate may be reduced to arsenite. Arsenite is more subject to leaching because of its higher solubility.

- **Chromium:** Chromium (Cr) can exist in soil in three forms: the trivalent Cr(III) form, Cr^{+3}, and the hexavalent Cr(VI) forms, $(Cr_2O_7)^{-2}$ and $(CrO_4)^{-2}$. Hexavalent chromium is the major chromium species used in industry; wood

preservatives commonly contain chromic acid, a Cr(VI) oxide. The two forms of hexavalent chromium are pH dependent; hexavalent chromium as a chromate ion $(CrO_4)^{-2}$ predominates above a pH of 6; dichromate ion $(Cr_2O_7)^{-2}$ predominates below a pH of 6. The dichromate ions present a greater health hazard than chromate ions, and both Cr(VI) ions are more toxic than Cr(III) ions.

Because of its anionic nature, Cr(VI) associates only with soil surfaces at positively charged exchange sites, the number of which decrease with increasing soil pH. Iron and aluminum oxide surfaces adsorb the chromate ion at an acidic or neutral pH.

Chromium (III) is the stable form of chromium in soil. Cr(III) hydroxy compounds precipitate at pH 4.5 and complete precipitation of the hydroxy species occurs at pH 5.5. In contrast to Cr(VI), Cr(III) is relatively immobile in soil. Chromium (III) does, however, form complexes with soluble organic ligands, which may increase its mobility.

Regardless of pH and redox potential, most Cr(VI) in soil is reduced to Cr(III). Soil organic matter and Fe(II) minerals donate the electrons in this reaction. The reduction reaction in the presence of organic matter proceeds at a slow rate under normal environmental pH and temperatures, but the rate of reaction increases with decreasing soil pH.

- **Copper:** Soil retains copper (Cu) through exchange and specific adsorption. Copper adsorbs to most soil constituents more strongly than any other toxic metal, except lead (Pb). Copper, however, has a high affinity to soluble organic ligands; the formation of these complexes may greatly increase its mobility in soil.

- **Lead:** Lead is a heavy metal that exists in three oxidation states: O, +2(II), and +4(IV). Lead is generally the most widespread and concentrated contaminant present at a lead battery recycling site (i.e., battery breaker or secondary lead smelter).

  Lead tends to accumulate in the soil surface, usually within 3 to 5 centimeters of the surface. Concentrations decrease with depth. Insoluble lead sulfide is typically immobile in soil as long as reducing conditions are maintained. Lead can also be biomethylated, forming tetramethyl and tetraethyl lead. These compounds may enter the atmosphere by volatilization.

  The capacity of soil to adsorb lead increases with pH, cation exchange capacity, organic carbon content, soil/water Eh (redox potential), and phosphate levels. Lead exhibits a high degree of adsorption on clay-rich soil. Only a small percent of the total lead is leachable; the major portion is usually solid or adsorbed onto soil particles. Surface runoff, which can transport soil particles containing adsorbed lead, facilitates migration and subsequent desorption from contaminated soils. On the other hand, groundwater (typically low in suspended soils and leachable lead salts) does not normally create a major pathway for lead migration. Lead compounds are soluble at low pH and at high pH, such as those

induced by solidification/stabilization treatment. Several other metals are also amphoteric, which strongly affects leaching. If battery breaking activities have occurred on-site, and the battery acid was disposed of on-site, elevated concentrations of lead and other metals may have migrated to groundwater.

- **Mercury:** In soils and surface waters, volatile forms (e.g., metallic mercury and dimethylmercury) evaporate to the atmosphere, whereas solid forms partition to particulates. Mercury exists primarily in the mercuric and mercurous forms as a number of complexes with varying water solubilities. In soils and sediments, sorption is one of the most important controlling pathways for removal of mercury from solution; sorption usually increases with increasing pH. Other removal mechanisms include flocculation, co-precipitation with sulfides, and organic complexation. Mercury is strongly sorbed to humic materials. Inorganic mercury sorbed to soils is not readily desorbed; therefore, freshwater and marine sediments are important repositories for inorganic mercury.

- **Zinc:** Clay carbonates, or hydrous oxides, readily adsorb zinc (Zn). The greatest percentage of total zinc in polluted soil and sediment is associated with iron (Fe) and manganese (Mn) oxides. Rainfall removes zinc from soil because the zinc compounds are highly soluble. As with all cationic metals, zinc adsorption increases with pH. Zinc hydrolyzes at a pH >7.7. These hydrolyzed species strongly adsorb to soil surfaces. Zinc forms complexes with inorganic and organic ligands, which will affect its adsorption reactions with the soil surface.

2.6.1.2 Radionuclides

For the purposes of this document, radionuclides should be considered to have properties similar to those of other heavy metals. (See the beginning of Subsection 2.6 for a list of typical radionuclides.) This does not imply that all radionuclides are heavy metals, but that the majority of sites requiring remediation of radioactively contaminated materials are contaminated with radionuclides that have similar properties. Like metals, the contaminants of concern are typically nonvolatile and less soluble in water than some other contaminants. However, the solubility and volatility of individual radionuclides will vary and should be evaluated for each wastestream being remediated. For example, cesium-137 is more volatile than uranium-238 and some cesium may volatilize, requiring off-gas treatment, when treated with processes at elevated temperatures (e.g., vitrification). Similarly, the mobility of radium-226, which is generally soluble in water under environmental conditions, will be greater than that of thorium-230, which is much less soluble.

Unlike organic contaminants (and similar to metals), radionuclides cannot be destroyed or degraded; therefore, remediation technologies applicable to radionuclides involve separation, concentration/volume reduction, and/or immobilization. Some special considerations when remediating sites contaminated with radionuclides include the following:

- Implementation of remediation technologies should consider the potential for radiological exposure (internal and external). The degree of hazard is based on the radionuclide(s) present and the type and energy of radiation emitted (i.e., alpha particles, beta particles, gamma radiation, and neutron radiation). The

design should take into account exposure considerations and the principles of keeping exposures as low as reasonably achievable (ALARA).

- Because radionuclides are not destroyed, ex situ techniques will require eventual disposal of residual radioactive wastes. These waste forms must meet disposal site waste acceptance criteria.

- There are different disposal requirements associated with different types of radioactive waste. Remediation technologies addressed in this document are generally applicable for low-level radioactive waste (LLW), transuranic waste (TRU), and/or uranium mill tailings. The technologies are not applicable to spent nuclear fuel and, for the most part, are not applicable for high-level radioactive waste.

- Some remediation technologies result in the concentration of radionuclides. By concentrating radionuclides, it is possible to change the classification of the waste, which impacts requirements for disposal. For example, concentrating radionuclides could result in LLW becoming TRU waste (if TRU radionuclides were concentrated to greater than 100 nanocuries/gm). Also, LLW classifications (e.g., Class A, B, or C for commercial LLW) could change due to the concentration of radionuclides. Waste classification requirements, for disposal of residual waste (if applicable), should be considered when evaluating remediation technologies.

- Disposal capacity for radioactive and mixed waste is limited. For example, commercial LLW disposal capacity will no longer be available for many out-of-compact (regions without a licensed LLW disposal facility) generators because the disposal facility in Barnwell, SC, closed (to out-of-compact generators) on 30 June 1994. Currently there is only one disposal facility (Envirocare of Utah, Inc.) licensed to accept mixed waste (i.e., low-activity mixed LLW and hazardous waste) for disposal. Mixed waste can be treated to address the hazardous characteristics of the soil, thereby allowing the waste to be addressed as solely a radioactive waste.

✍ 2.6.2 Common Treatment Technologies for Inorganics in Soil, Sediment, and Sludge

The most commonly used treatment technologies for inorganics in soil, sediment, and sludge include solidification/stabilization (S/S), and excavation and off-site disposal. These treatment technologies are described briefly below.

Solidification processes produce monolithic blocks of waste with high structural integrity. The contaminants do not necessarily interact chemically with the solidification reagents (typically cement/ash) but are mechanically locked within the solidified matrix. Stabilization methods usually involve the addition of materials such as fly ash, which limit the solubility or mobility of waste constituents—even though the physical handling characteristics of the waste may not be changed or improved. Methods involving S/S techniques are often proposed in RODs and RI/FSs for lead battery recycling sites. Solidification/stabilization of contaminated soil can be conducted either in situ or ex situ. In situ S/S techniques are now

considered innovative and are discussed in Section 4.

Excavation and removal of contaminated soil (with or without stabilization) to a landfill have been performed extensively at many sites. Landfilling of hazardous materials, especially hazardous wastes, is becoming increasingly difficult and expensive as a result of growing regulatory control, and may be cost-prohibitive for sites with large volumes, greater depths, or complex hydrogeologic environments. In addition, disposal capacity for radioactive and mixed waste is extremely limited. Determining the feasibility of off-site disposal requires knowledge of land disposal restrictions and other regulations developed by state governments.

✍ 2.6.3 Common Treatment Technologies for Inorganics in Groundwater, Surface Water, and Leachate

In addition to the general data requirements discussed in Subsection 2.2.2, it may be necessary to know other subsurface information to remediate inorganics in groundwater, surface water, and leachate. **Treatability studies** are usually necessary to ensure that the contaminated groundwater can be treated effectively at the design flow. A **subsurface geologic** characterization would be particularly important to characterize the effects of adsorption and other processes of attenuation. **Groundwater models** are also often needed to predict flow characteristics, changes in contaminant mixes and concentrations, and times to reach action levels.

Precipitation, filtration, and ion exchange are widely used ex situ treatment technologies for inorganics in groundwater and are discussed in the following paragraphs. In situ treatment technologies are used less frequently.

The combination of **precipitation/flocculation** and sedimentation is a well-established technology for metals and radionuclides removal from groundwater. This technology pumps groundwater through extraction wells and then treats it to precipitate lead and other heavy metals. Typical removal of metals employs precipitation with hydroxides, carbonates, or sulfides. Hydroxide precipitation with lime or sodium hydroxide is the most common choice. Generally, the precipitating agent is added to water in a rapid-mixing tank along with flocculating agents such as alum, lime, and/or various iron salts. This mixture then flows to a flocculation chamber that agglomerates particles, which are then separated from the liquid phase in a sedimentation chamber. Other physical processes, such as filtration, may follow.

Metal sulfides exhibit significantly lower solubility than their hydroxide counterparts, achieve more complete precipitation, and provide stability over a broad pH range. At a pH of 4.5, sulfide precipitation can achieve the EPA-recommended standard for potable water. Sulfide precipitation, however, can be considerably more expensive than hydroxide precipitation, as a result of higher chemical costs and increased process complexity; also, there are safety concerns associated with the possibility of H_2S emissions. The precipitated metals would be handled in a manner similar to contaminated soils. The supernatant would be discharged to a nearby stream, a POTW, or recharged to upstream of site aquifer. Selection of the most suitable precipitant or flocculent, optimum pH, rapid mix

requirements, and most efficient dosages is determined through laboratory jar test studies.

Filtration isolates solid particles by running a fluid stream through a porous medium. The driving force is either gravity or a pressure differential across the filtration medium. Pressure differentiated filtration techniques include separation by centrifugal force, vacuum, or positive pressure. The chemicals are not destroyed; they are merely concentrated, making reclamation possible. Parallel installation of double filters is recommended so groundwater extraction or injection pumps do not have to stop operating when filters backwashed.

Ion exchange is a process whereby the toxic ions are removed from the aqueous phase in an exchange with relatively innocuous ions (e.g., NaCl) held by the ion exchange material. Modern ion exchange resins consist of synthetic organic materials containing ionic functional groups to which exchangeable ions are attached. These synthetic resins are structurally stable and exhibit a high exchange capacity. They can be tailored to show selectivity towards specific ions. The exchange reaction is reversible and concentration-dependent; the exchange resins are regenerable for reuse. The regeneration step leads to a 2 to 10% wastestream that must be treated separately.

All metallic elements present as soluble species, either anionic or cationic, can be removed by ion exchange. A practical influent upper concentration limit for ion exchange is about 2,000 mg/L. A higher concentration results in rapid exhaustion of the resin and inordinately high regeneration costs.

✍ 2.7 EXPLOSIVES

Sites where explosive contaminants may be found include artillery/impact areas, contaminated marine sediments, disposal wells, leach fields, landfills, burial pits, and TNT washout lagoons. Potentially applicable remediation technologies are presented in Table 2-5. Typical explosive contaminants encountered at many sites include the following:

- TNT
- RDX
- Tetryl
- 2,4-DNT
- 2,6-DNT
- HMX
- Nitroaromatics
- Picrates
- TNB
- DNB
- Nitroglycerine
- Nitrocellulose
- AP
- Nitroglycerine

TABLE 2-5 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF EXPLOSIVES

Technology (Text Section and Title)	Development Status	Use Rating	Applicability*	Technology Function*
SOIL, SEDIMENT, AND SLUDGE				
3.1 IN SITU BIOLOGICAL TREATMENT				

	4.1 Biodegradation	Pilot	Limited	Better	Destruct
	4.3 White Rot Fungus	Pilot	Limited	Better	Destruct
3.4	**EX SITU BIOLOGICAL TREATMENT (ASSUMING EXCAVATION)**				
	4.10 Composting	Full	Limited	Better	Destruct
	4.11 Cont. Solid Phase Bio. Treat.	Pilot	Limited	Better	Destruct
	4.12 Landfarming	Pilot	Limited	Average	Destruct
	4.13 Slurry Phase Bio. Treatment	Pilot	Limited	Better	Destruct
3.5	**EX SITU PHYSICAL/CHEMICAL TREATMENT (assuming excavation)**				
	4.17 Soil Washing	Pilot	Limited	Better	Extract
	4.20 Solvent Extraction	Pilot	Limited	Better	Extract
3.6	**EX SITU THERMAL TREATMENT (ASSUMING EXCAVATION)**				
	4.22 Hot Gas Decontamination	Pilot	Limited	Better	Destruct
	4.23 Incineration	Full	Wide	Better	Destruct
	4.24 Low Temp. Thermal Desorption	Full	Limited	Better	Destruct
	4.25 Open Burn/Detonation	Pilot	Wide	Average	Destruct
3.7	**OTHER TREATMENT**				
	4.28 Excavation/Off-Site Disp.	NA	Limited	Average	Extract/Immob.
GROUNDWATER, SURFACE WATER, AND LEACHATE					
3.8	**IN SITU BIOLOGICAL TREATMENT**				
	4.30 Co-Metabolic Treatment	Pilot	Limited	Average	Destruct
	4.31 Nutrient Enhancement	Pilot	Limited	Average	Destruct
	4.32 Oxygen Enhance. Air	Pilot	Limited	Average	Destruct
	4.33 Oxygen Enhance. w/H_2O_2	Pilot	Limited	Average	Destruct
3.9	**IN SITU PHYSICAL/CHEMICAL TREATMENT**				
	4.40 Passive Treatment Walls	Pilot	Limited	Better	Extract
	4.41 Slurry Walls	Full	Limited	Better	Immobilize
3.10	**EX SITU BIOLOGICAL TREATMENT**				
	4.43 Bioreactors	Pilot	Limited	Average	Destruct
3.11	**EX SITU PHYSICAL/CHEMICAL TREATMENT (ASSUMING PUMPING)**				
	4.45 Filtration	Full	Limited	Average	Extract
	4.47 Liquid Phase Carbon Adsorption	Full	Wide	Better	Extract
	4.49 UV Oxidation	Full	Limited	Better	Destruct

*The following rankings are discussed in Table 3-1 and Figure 3-1.

✍ 2.7.1 Properties and Behavior of Explosives

Information presented for SVOCs (Subsection 2.4.1) may also be appropriate for many of the contaminants presented in this subsection.

The term "explosive waste" commonly is used to refer to propellants, explosives, and pyrotechnics (PEP), which technically fall into the more general category of energetic materials. These materials are susceptible to initiation, or self-sustained energy release, when present in sufficient quantities and exposed to stimuli such as heat, shock, friction, chemical incompatibility, or electrostatic discharge. Each of these materials reacts differently to the aforementioned stimuli; all will burn, but explosives and propellants can detonate under certain conditions (e.g., confinement). Figure 2-1 outlines the various categories of energetic materials. The emphasis of this document is on soil and groundwater contaminated with explosives rather than propellants, pyrotechnics, or munitions.

Explosives are classified as primary or secondary based on their susceptibility to initiation. Primary explosives, which include lead azide and lead styphnate, are highly susceptible to initiation. Primary explosives often are referred to as initiating explosives because they can be used to ignite secondary explosives.

Secondary explosives, which include TNT, cyclo-1,3,5-trimethylene-2,4,6-trinitramine (RDX or cyclonite), high melting explosives (HMX), and tetryl, are much more prevalent at military sites than are primary explosives. Because they are formulated to detonate only under specific circumstances, secondary explosives often are used as main charge or bolstering explosives. Secondary explosives can be loosely categorized into melt-pour explosives, which are based on TNT, and plastic-bonded explosives (PBX), which are based on a binder and crystalline explosive such as RDX. Secondary explosives also can be classified according to their chemical structure as nitroaromatics, which include TNT, and nitramines, which include RDX. In the TNT molecule, NO_2 groups are bonded to the aromatic ring; in the RDX molecule, NO_2 groups are bonded to nitrogen.

FIGURE 2-1 CATEGORIES OF ENERGETIC MATERIALS

Propellants include both rocket and gun propellants. Most rocket propellants are either Hazard Class 1.3 composites, which are based on a rubber binder, and ammonium perchlorate (AP) oxidizer, and a powdered aluminum (Al) fuel; or Hazard Class 1.1 composites, which are based on a nitrate ester, usually nitroglycerine (NG), nitrocellulose (NC), HMX, AP, or polymer-bound low NC. If a binder is used, it usually is an isocyanate-cured polyester or polyether. Some propellants contain combustion modifiers, such as lead oxide.

Gun propellants usually are single base (NC), double base (NC and NG), or triple base [NC, NG, and nitroguanidine (NQ)]. Some of the newer, lower vulnerability gun propellants contain binders and crystalline explosives and thus are similar to PBX.

Pyrotechnics include illuminating flares, signaling flares, colored and white smoke generators, tracers, incendiary delays, fuses, and photo-flash compounds. Pyrotechnics usually are composed of an inorganic oxidizer and metal powder in a binder. Illuminating flares contain sodium nitrate, magnesium, and a binder. Signaling flares contain barium, strontium, or other metal nitrates.

Safety precautions must be taken at sites contaminated with explosive wastes to avoid initiation. USAEC, which has been involved in sampling and treating explosives waste sites since the early 1980s, has developed protocols for identifying sites that require explosives safety precautions and for handling explosives wastes at these sites.

Under its current protocol, USAEC can determine quickly and inexpensively whether materials are susceptible to initiation and propagation by analyzing the composition of samples from the site. According to the deflagration-to-detonation test, soils containing more than 12% secondary explosives by weight are susceptible to initiation by flame; according to the shock gap test, soils containing more than 15% secondary explosives by weight are susceptible to initiation by shock. As a conservative limit, USAEC considers all soils containing more than 10% secondary explosives by weight to be susceptible to initiation and propagation and exercises a number of safety precautions when sampling and treating these soils. Sampling and treatment precautions are exercised when handling soils that contain even minute quantities of primary explosives.

Work, sampling, and health and safety plans for explosives waste sites should incorporate safety provisions that normally would not be included in work and sampling plans for other sites. The most important safety precaution is to minimize exposure, which involves minimizing the number of workers exposed to hazardous situations, the duration of exposure, and the degree of hazard.

✍ 2.7.2 Common Treatment Technologies for Explosives in Soil, Sediment, and Sludge

The U.S. Army operates explosives manufacturing plants to produce various forms of explosives used in military ordnance. Manufacturing activities at such plants result in the production of organic wastewaters that contain both explosive residues and other organic chemicals. Past waste handling practices at such plants

commonly included the use of unlined lagoons or pits for containing process waters. As a result of these past practices, some explosive residues may leach through the soil and contaminate groundwater.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and the Missouri River Division (MRD) have been involved with numerous explosives-contaminated sites. They have compiled data on the frequency of nitroaromatics and nitramines detected in explosives-contaminated soils from Army sites. TNT is the most common contaminant, occurring in approximately 80% of the soil samples found to be contaminated with explosives. Trinitrobenzene (TNB), which is a photochemical decomposition product of TNT, was found in between 40 and 50% of these soils. Dinitrobenzene (DNB), 2,4-dinitrotoluene (2,4-DNT), and 2,6-DNT, which are impurities in production-grade TNT, were found in less than 40% of the soils.

As mentioned earlier, safety concerns are an important consideration when discussing remediation of explosives-contaminated soils, sediments, and sludges. Spark and static electricity hazards must be eliminated. Nonsparking tools, conductive and grounded plastic, and no-screw tops, which were developed for manufacturing explosives, are standard equipment at explosive waste sites. For example, nonsparking beryllium tools are used instead of ferrous tools.

If contamination is above the 10% limit in some areas of a site, the contaminated material could be blended and screened to dilute the contamination and produce a homogenous mixture below the 10% limit. This blending is not by itself a remedial action but a safety precaution; soils containing less than 10% secondary explosives by weight occasionally experience localized detonations, but generally resist widespread propagation. Foreign objects and unexploded ordnance within the contaminated soil often impede the blending process and require specialized unexploded ordnance management procedures.

Once blending is completed, soil treatments such as incineration and bioremediation can proceed. Equipment used in treatment must have sealed bearings and shielded electrical junction boxes. Equipment also must be decontaminated frequently to prevent the buildup of explosive dust.

Biological, thermal, and other (such as reuse/recycle) treatment technologies are available to treat explosives-contaminated soils. These technologies are briefly discussed below.

2.7.2.1 Biological Treatment Technologies

Biological treatment, or bioremediation, is a developing technology that uses microorganisms to degrade organic contaminants into less hazardous compounds. Bioremediation is most effective for dilute solutions of explosives and propellants. TNT in the crystalline form is difficult to treat biologically.

TNT degrades under aerobic conditions into monoamine-, diamino-, hydroxylamine-DNT, and tetranitro-azoxynitrotoluenes. RDX and HMX degrade into carbon dioxide and water under anaerobic conditions. Researchers have not identified any

specific organisms that are particularly effective for degrading explosives waste; an indigenous consortium of organisms usually affects the degradation.

DOD currently is developing or implementing five biological treatments for explosives-contaminated soils: aqueous-phase bioreactor treatment; composting, land farming, and white rot fungus treatment, which are solid-phase treatments; and in situ biological treatment.

Aqueous Phase Bioreactor Treatment: DOD is considering two types of aqueous-phase bioreactors for the treatment of explosive contaminants. The first is the lagoon slurry reactor, which allows contaminants to remain in a lagoon, be mixed with nutrients and water, and degrade under anaerobic conditions. The lagoon slurry reactor is still in the development stage. The second is the aboveground slurry reactor, which is either constructed on-site or purchased as a package plant.

Aqueous-phase bioreactors provide good process control, can be configured in several treatment trains to treat a variety of wastes, and potentially can achieve very low contaminant concentrations. A drawback of bioreactor treatment is that, unlike composting systems which bind contaminants to humic material, bioreactors accumulate the products of biotransformation. In addition, bioreactors have been shown to remediate explosives only at laboratory scale, so the cost of full-scale bioreactors will have to incorporate a variety of safety features that will add to their total cost.

Composting: DOD has been evaluating composting systems to treat explosives waste since 1982. To date, composting has been shown to degrade TNT, RDX, HMX, DNT, tetryl, and nitrocellulose in soils and sludges. The main advantage of this technology is that, unlike incineration, composting generates an enriched product that can sustain vegetation. After cleanup levels are achieved, the compost material can be returned to the site. Another advantage is that composting is effective for a range of wastes. The cost of composting can be limited, however, by the level of indigenous organisms in contaminated soil and the local availability of amendment mixtures. In addition, composting requires long treatment periods for some wastestreams, and composting of unfamiliar contaminants potentially can generate toxic byproducts.

Composting methods fall into three categories: static-pile composting; mechanically agitated, in-vessel composting; and windrow composting. In static-pile composting, contaminated material is excavated, placed in a pile under protective shelter, and mixed with readily degradable carbon sources. The pile undergoes forced aeration to maintain aerobic and thermophilic (55 to 60 ?C or 131 to 140 ?F) conditions, which foster the growth of microorganisms. Bulking agents, such as cow manure and vegetable waste and/or wood chips, can be added to enhance biodegradation. In mechanically agitated, in-vessel composting, contaminated material is aerated and blended with carbon-source materials in a mechanical composter. These devices have been used at municipal sewage treatment facilities and applied to explosives waste. Windrow composting is similar to static-pile composting except that compost is aerated by a mechanical mixing vehicle, rather than a forced air system.

Land Farming: Land farming has been used extensively to treat soils contaminated with petroleum hydrocarbons, pentachlorophenol (PCP), and polycyclic aromatic hydrocarbons (PAHs), and potentially could be used to treat low to medium concentrations of explosives as well. In land farming, soils are excavated to treatment plots and periodically tilled to mix in nutrients, moisture, and bacteria. In one pilot study at an explosives waste site in Hercules, California, land farming failed to achieve the target cleanup levels of 30-ppm TNT, 5-ppm DNT, and 5-ppm DNB. The study achieved a 30 to 40% contaminant degradation.

White Rot Fungus Treatment: White rot fungus, *Phanerochaete chrysosporium*, has been evaluated more extensively than any other fungal species for remediating explosives-contaminated soil. Although white rot has been reported in laboratory-scale settings using pure cultures (Berry and Boyd, 1985; Fernando et al., 1990), a number of factor increase the difficulty of using this technology for full-scale remediation. These factors include competition from native bacterial populations, toxicity inhibition, chemical sorption, and the inability to meet risk-based cleanup levels.

In bench-scale studies of mixed fungal and bacterial systems, most of the reported degradation of TNT is attributable to native bacterial populations (Lohr, 1993; McFarland et al., 1990). High TNT concentrations in soil also can inhibit growth of white rot fungus. One study suggested that *Phanerochaete chrysosporium* was incapable of growing in soils contaminated with 20 ppm or more of TNT. In addition, some reports indicate that TNT losses reported in white rot fungus studies can be attributed to adsorption of TNT onto the fungus and soil amendments, such as corn cobs and straw.

In Situ Biological Treatment: In situ treatments can be less expensive than other technologies and produce low contaminant concentrations. The available data suggest, however, that in situ treatment of explosives might create more mobile intermediates during biodegradation. In addition, biodegradation of explosive contaminants typically involves metabolism with an added nutrient source, which is difficult to deliver in an in situ environment. Mixing often affects the rate and performance of explosives degradation. Finally, effectiveness of in situ treatment is difficult to verify both during and after treatment.

2.7.2.2 Thermal Treatment Technologies

Incineration: Incineration processes can be used to treat the following wastestreams: explosive-contaminated soil and debris, explosives with other organic or metals, initiating explosives, some bulk explosives, unexploded ordnance, bulk explosive waste, and pyrophoric waste. In addition, incineration can be applied to sites with a mixture of media, such as sand, clay, water, and sludge, provided the media can be fed to the incinerator and heated for a sufficient period of time. With the approval of the DOD Explosives Safety Board, the Army considers incineration of materials containing less than 10% explosives by weight to be a nonexplosive operation. Soil with less than 10% explosives by weight has been shown by USAEC to be nonreactive; that is, not to propagate a detonation throughout the mass of soil. (The military explosives to which this limit applies are secondary explosives such as TNT and RDX and their manufacturing byproducts).

The Army primarily uses three types of incineration devices: the rotary kiln incinerator, deactivation furnace, and contaminated waste processor.

The rotary kiln incinerator is used primarily to treat explosives-contaminated soils. In rotary kiln incineration, soils are fed into a primary combustion chamber, or rotary kiln, where organic constituents are destroyed. The temperature of gases in the primary chamber ranges from 427 to 649 ?C (800 to 1,200 ?F), and the temperature of soils ranges from 316 to 427 ?C (600 to 800 ?F). Retention time in the primary chamber, which is varied by changing the rotation speed of the kiln, is approximately 30 minutes. Off gases from the primary chamber pass into a secondary combustion chamber, which destroys any residual organics. Gases from the secondary combustion chamber pass into a quench tank where they are cooled from approximately 2,000 to 200 ?C (3,600 to 400 ?F). From the quench tank, gases pass through a Venturi scrubber and a series of baghouse filters, which remove particulates prior to release from the stack. The treated product of rotary kiln incineration is ash (or treated soil), which drops from the primary combustion chamber after organic contaminants have been destroyed. This product is routed into a wet quench or a water spray to remoisturize it, then transported to an interim storage area pending receipt of chemical analytical results.

The deactivation furnace is also referred to as Army Peculiar Equipment (APE) 1236 because it is used almost exclusively by the Army to deactivate large quantities of small arms cartridges, and 50-caliber machine gun ammunition, mines, and grenades. The deactivation furnace is similar to the rotary kiln incinerator except it is equipped with a thick-walled primary combustion chamber capable of withstanding small detonations. Deactivation furnaces do not have secondary combustion chambers because they are intended not to completely destroy the vaporized explosives but to render the munitions unreactive. Most deactivation furnaces are equipped with air pollution control equipment to limit lead emissions. The operating temperature of deactivation furnaces is approximately 650 to 820 ?C (1,200 to 1,500 ?F).

The contaminated waste processor handles materials, such as surface-contaminated debris, that are lighter and less reactive than those processed in the deactivation furnace. Contaminated waste processors are thin-walled, stationary ovens that heat contaminated materials to about 600 ?C (1,100 ?F) for 3 to 4 hours. The purpose of this process is not to destroy contaminated debris but to sufficiently lower contaminant levels through volatilization to meet Army safety standards. USAEC currently is helping to develop standardized time and temperature processing requirements to meet these safety standards.

Open Burn/Open Detonation: Open burn (OB) and open detonation (OD) operations are conducted to destroy unserviceable, unstable, or unusable munitions and explosive materials. In OB operations, explosives or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as flame, heat, or a detonation wave. In OD operations, detonable explosives and munitions are destroyed by a detonation initiated by a disposal charge. OB/OD operations require regulatory permits. These permits must be obtained from the appropriate regulatory agency on a case-by-case basis.

OB/OD operations can destroy many types of explosives, pyrotechnics, and propellants. OB areas must be able to withstand accidental detonation of any or all explosives being destroyed, unless the characteristic of the materials involved is such that orderly burning without detonation can be ensured. Personnel with this type of knowledge must be consulted before any attempt is made at OB disposal, especially if primary explosives are present in any quantity.

OB and OD can be initiated either by electric or burning ignition systems. In general, electric systems are preferable because they provide better control over the timing of the initiation. In an electric system, electric current heats a bridge wire, which ignites a primary explosive or pyrotechnic to, in turn, ignite or detonate the material slated to be burned or detonated. If necessary, safety fuses, which consist of propellants wrapped in plastic weather stripping, are used to initiate the burn or detonation.

2.7.2.3 Other Treatment Technologies

Reuse/Recycle: Recovery and reuse technologies for energetic materials, including both explosives and propellants, should be considered at explosives waste sites for several reasons. First, new recovery methods and potential uses for reclaimed explosive materials are rapidly developing. Second, recovery/reuse options reduce overall remediation costs by eliminating destruction costs and allowing the value of reclaimed materials to be recovered. Finally, EPA's treatment hierarchy, which is based on environmental considerations, favors recovery/reuse options over destruction technologies.

Soils and sludges contaminated with energetic materials present handling problems during recovery and reuse operations. USAEC has established a guideline that soils containing greater than 10% energetic materials by weight should be considered explosive during handling and transportation. As a general rule, soils and sludges containing less than 10% energetic materials by weight pass USAEC's nonreactivity tests. Reuse/recycle options are more feasible for contaminated soils and sludges meeting the nonreactivity criteria because they can be removed, transported, and handled using conventional equipment, which could provide a substantial cost savings.

Solvent Extraction: Solvent extraction is a technology that the Army originally determined to be infeasible for treating explosives-contaminated soils. The technology, however, might have potential for treating these soils if a few lingering technical issues can be resolved. In 1982, the Army conducted laboratory-scale solvent extraction on explosives-contaminated lagoon samples from a number of sites. Each sample was washed with a solution of 90% acetone and 10% water. This process achieved greater than 99% contaminant removals.

In 1985, the Army conducted a pilot-scale engineering analysis to determine the feasibility of full-scale solvent extraction. This analysis indicated that, for solvent extraction to be economically feasible, the number of required washes would have to be reduced, and acetone would have to be recovered and reused. Currently, the only available technology for recovering acetone is distillation, which exposes acetone to

heat and pressure. Exposing a solvent that has been used to extract explosive contaminants to heat and pressure raises serious safety considerations. In fact, the distillation column used to recover acetone often is referred to as an "acetone rocket." Nevertheless, the Army believes that full-scale solvent extraction would be feasible if a safe, efficient, alternative recovery method were developed.

Soil Washing: A soil washing procedure, termed the Lurgi Process, currently is being developed in Stadtalendorf, Germany. Although no data have been published on the effectiveness of this process, initial reports suggest that the process can reduce levels of explosive contamination in soils to low ppm levels. As with all soil washing technologies, the Lurgi Process produces secondary wastes, such as washwater and concentrated explosives.

In the Lurgi Process, contaminated soils are excavated and processed in an attrition reactor, which detaches the explosive material from the soil particles. The remaining material undergoes a second process, which separates clean from contaminated particles. Clean particles are dewatered, separated into heavy and light materials, and returned to the site. Contaminated particles undergo a final series of washing, separation, and chemical extraction processes to remove any remaining clean particles. Finally, the contaminated material is clarified and concentrated before being disposed of or treated.

✍ 2.7.3 Common Treatment Technologies for Explosives in Groundwater, Surface Water, and Leachate

Explosives-contaminated process waste waters can be subdivided into two categories: red water, which comes strictly from the manufacture of TNT, and pink water, which includes any washwater associated with load, assemble, and pack (LAP) operations or with the demilitarization of munitions involving contact with finished explosive. Despite their names, red and pink water cannot be identified by color. Both are clear when they emerge from their respective processes and subsequently turn pink, light red, dark red, or black when exposed to light. The chemical composition of pink water varies depending on the process and explosive operation from which it is derived; red water has a more defined chemical composition. For this reason, it is not possible to simulate either red or pink water in the laboratory.

The United States stopped production of TNT in the mid-1980s, so no red water has been generated in this country since that date (Hercules Aerospace Company, 1991). Most process waters found in the field are pink waters that were generated by LAP and demilitarization operations conducted in the 1970s. In these operations, munitions were placed on racks with their fuses and tops removed. Jets of hot water then were used to mine the explosives out of the munitions. The residual waters were placed in settling basins so that solid explosive particles could be removed, and the remaining water was transferred into lagoons. Contaminants often present in these lagoon waters and the surrounding soils include TNT, RDX, HMX, 2,4-DNT, 2,6-DNT, 1,3-DNB, 1,3,5-TNB, and nitrobenzene.

These past waste-handling practices at explosives manufacturing and LAP plants often used unlined lagoons or pits to contain process wastewaters. As a result of

this practice, some explosive residues have leached through the soil and contaminated groundwater. Therefore, groundwater treatment may be required. Based upon process wastewater treatment experience, potentially applicable treatment technologies are available. However, the similarities and differences between process wastewaters and explosives-contaminated groundwater should be considered before transferring technologies from one application to another.

Granular-activated carbon (GAC) adsorption is commonly used for explosives-contaminated groundwater treatment. GAC does not work for red water treatment.

In the 1980s, the Army discontinued the practice of disposing of untreated process waters from the production and maintenance of munitions in open lagoons. Every Army ammunition plant currently employs some type of GAC system to treat process waters as they are generated. GAC is very effective at removing a wide range of explosive contaminants from water.

GAC can be used to treat explosives-contaminated water, including process waters from the manufacture and demilitarization of munitions (pink water) and groundwater contaminated from disposal of these waters.

Ultraviolet (UV) oxidation has not been used extensively for remediating water contaminated with explosives because of the widespread use of GAC treatment. Nevertheless, UV oxidation can be an effective treatment for explosives-contaminated water and, unlike carbon treatment, actually destroys target compounds rather than just transferring them to a more easily disposable medium. UV oxidation can be used to treat many types of organic explosives-contaminated water, including process waters from the demilitarization of munitions (pink water) and groundwater contaminated from disposal of these process waters.

USAE-WES is currently evaluating a perozone system for explosives-contaminated groundwater treatment. This system uses hydrogen peroxide and ozone to oxidize explosive constituents without UV light. The perozone system may offer economic advantages in UV oxidation systems.

Section 3
TREATMENT PERSPECTIVES

Three primary strategies used separately or in conjunction to remediate most sites are:

- Destruction or alteration of contaminants.
- Extraction or separation of contaminants from environmental media.
- Immobilization of contaminants.

Treatment technologies capable of contaminant destruction by altering their chemial structure are thermal, biological, and chemical treatment methods. These destruction technologies can be applied in situ or ex situ to contaminated media.

Treatment technologies commonly used for extraction and separation of contaminants from environmental media include soil treatment by thermal desorption, soil washing, solvent extraction, and soil vapor extraction (SVE) and groundwater treatment by either phase separation, carbon adsorption, air stripping, ion exchange, or some combination of these technologies. Selection and integration of technologies should use the most effective contaminant transport mechanisms to arrive at the most effective treatment scheme. For example, more air than water can be moved through soil. Therefore, for a volatile contaminant in soil that is relatively insoluble in water, SVE would be a more efficient separation technology than soil flushing or washing.

Immobilization technologies include stabilization, solidification, and containment technologies, such as placement in a secure landfill or construction of slurry walls. No immobilization technology is permanently effective, so some type of maintenance is desired. Stabilization technologies are often proposed for remediating sites contaminated by metals or other inorganic species.

FIGURE 3-1 CLASSIFICATION OF REMEDIAL TECHNOLOGIES BY FUNCTION

These concepts about site remediation strategies and representative technologies associated with them are summarized in Figure 3-1. One feature obvious from the figure is that the choice of applied technologies is not extensive once a strategy is selected.

Generally, no single technology can remediate an entire site. Several treatment technologies are usually combined at a single site to form what is known as a *treatment train*. SVE can be integrated with groundwater pumping and air stripping to simultaneously remove contaminants from both groundwater and soil. The emissions from the SVE system and the air stripper can be treated in a single air treatment unit. An added benefit is that the air flow through the soil stimulates or enhances natural biological activity, and some biodegradation of contaminants occurs. In some cases, air is injected into either the saturated or the unsaturated zones to facilitate contaminant transport and to promote biological activity.

For the purpose of this document, the technologies are separated into 13 treatment groups as follows:

· Soil, sediment, and sludge:

- In situ biological treatment.
- In situ physical/chemical treatment.
- In situ thermal treatment.
- Ex situ biological treatment (assuming excavation).
- Ex situ physical/chemical treatment (assuming excavation).
- Ex situ thermal treatment (assuming excavation).
- Other treatment processes.

· Groundwater, surface water, and leachate:

- In situ biological treatment.
- In situ physical/chemical treatment.
- Ex situ biological treatment (assuming pumping).
- Ex situ physical/chemical treatment (assuming pumping).
- Other treatment processes.

· Air emissions/off-gas treatment.

These 13 treatment groups correspond to the following 13 subsections (3.1 through 3.13). The discussion of the broad application of each treatment group (e.g., in situ biological treatment for soil, sediment, and sludge) in this section is followed by a more detailed discussion of each treatment technology (e.g., bioventing) in that treatment group, in Section 4. Information on completed projects in these treatment process areas has been presented in tables extracted from the *Innovative Treatment Technologies Annual Status Report*, EPA, 1993, and the *Synopses of Federal Demonstrations of Innovative Site Remediation Technologies*, FRTR, 1993.

Tables 3-1 and 3-2 summarize pertinent information for each of the treatment technologies presented in Section 4. Information summarized includes the following:

· Technology Profile number (refers to Section 4).
· Scale status (full scale vs. pilot scale).
· Availability.
· Residuals produced.
· Typically treatment train.
· Contaminants treated.
· System reliability/maintainability.
· Cleanup time.
· Overall cost.
· Capital or O&M-intensive.

Additionally, a brief description of each treatment technology is presented in Table 3-3.

TABLE 3-1
DEFINITION OF SYMBOLS USED IN THE TREATMENT TECHNOLOGIES SCREENING MATRIX

Factors and Definitions	Worse	Average	Better
Availability Number of vendors that can design, construct, and maintain the technology.	Fewer than 2 vendors	2-4 vendors	More than 4 vendors
Contaminants Treated	No expected effectiveness	Either limited effectiveness or nontarget (e.g., VOC treatment by thermally enhanced SVE)	This contaminant is a treatment target of this technology
System Reliability/Maintainability The degree of system reliability and level of maintenance required when using the technology.	Low reliability and high maintenance	Average reliability and average maintenance	High reliability and low maintenance
Cleanup Time Time required to clean up a "standard" site using the technology. The "standard" site is assumed to be 20,000 tons (18,200 metric tons) for soils and 1 million gallons (3,785,000 liters) for groundwater.	More than 3 years for in situ soil More than 1 year for ex situ soil More than 10 years for water	1-3 years 0.5-1 year 3-10 years	Less than 1 year Less than 0.5 year Less than 3 years
Overall Cost Design, construction, and operations and maintenance (O&M) costs of the core process that defines each technology, exclusive of mobilization, demobilization, and pre- and post-treatment. For ex situ soil, sediment, and sludge technologies, it is assumed that excavation costs average $55.00/metric ton ($50/ton). For ex situ groundwater technologies, it is assumed that pumping costs average $0.07/1,000 liters ($0.25/1,000 gallons).	More than $330/metric ton ($300/ton) for soils More than $2.64/1,000 liters ($10/1,000 gal.) for groundwater More than $11.33/kg ($25/lb) for air emissions and off-gases	$110-$330/metric ton ($100-$300/ton) $0.79-$2.64/1,000 liters ($3.00 -$10.00/1,000 gallons) $3.17-$11.33/kg ($7-$25/lb)	Less than $110/metric ton ($100/ton) Less than $0.79/1,000 liters ($3.00/1,000 gallons) Less than $3.17/kg ($7/lb)

Source: ***Remediation Technologies Screening Matrix and Reference Guide*, Version I (EPA, USAF, 1993).**

TABLE 3-2 REMEDIATION TECHNOLOGIES SCREENING MATRIX

graphic

TABLE 3-3
DEFINITION OF MATRIX TREATMENT TECHNOLOGIES

Technology	Description
SOIL, SEDIMENT, AND SLUDGE	
In Situ Biological Treatment	
Biodegradation	The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance in situ biological degradation of organic contaminants. Nutrients, oxygen, or other amendments may be used to enhance biodegradation and contaminant desorption from subsurface materials.
Bioventing	Oxygen is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.
White Rot Fungus	White rot fungus has been reported to degrade a wide variety of organopollutants by using their lignin-degrading or wood-rotting enzyme system. Two different treatment configurations have been tested for white rot fungus, in situ and bioreactor.
In Situ Physical/Chemical Treatment	
Pneumatic Fracturing	Pressurized air is injected beneath the surface to develop cracks in low permeability and over-consolidated sediments, opening new passageways that increase the effectiveness of many in situ processes and enhance extraction efficiencies.
Soil Flushing	Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the groundwater to raise the water table into the contaminated soil zone. Contaminants are leached into the groundwater, which is then extracted and treated.
Soil Vapor Extraction	Vacuum is applied through extraction wells to create a pressure/concentration gradient that induces gas-phase volatiles to diffuse through soil to extraction wells. The process includes a system for handling off-gases. This technology also is known as in situ soil venting, in situ volatilization, enhanced volatilization, or soil vacuum extraction.
Solidification/ Stabilization	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).
In Situ Thermal Treatment	
Thermally Enhanced Soil Vapor Extraction	Steam/hot air injection or electric/radio frequency heating is used to increase the mobility of volatiles and facilitate extraction. The process includes a system for handling off-gases.
Vitrification	Electrodes for applying electricity are used to melt contaminated soils and sludges, producing a glass and crystalline structure with very low leaching characteristics.

TABLE 3-3
DEFINITION OF TREATMENT MATRIX TECHNOLOGIES (CONTINUED)

Technology	Description
Ex Situ Biological Treatment (assuming excavation)	
Composting	Contaminated soil is excavated and mixed with bulking agents and organic amendments such as wood chips, animal and vegetative wastes, which are added to enhance the porosity and organic content of the mixture to be decomposed.
Controlled Solid Phase Biological Treatment	Excavated soils are mixed with soil amendments and placed in aboveground enclosures. Processes include prepared treatment beds, biotreatment cells, soil piles, and composting.
Landfarming	Contaminated soils are applied onto the soil surface and periodically turned over or tilled into the soil to aerate the waste.
Slurry Phase Biological Treatment	An aqueous slurry is created by combining soil or sludge with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the soil contaminants. Upon completion of the process, the slurry is dewatered and the treated soil is disposed of.
Ex Situ Physical/Chemical Treatment (assuming excavation)	
Chemical Reduction/ Oxidation	Reduction/oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.
Base Catalyzed Decomposition Dehalogenation	Contaminated soil is screened, processed with a crusher and pug mill, and mixed with NaOH and catalysts. The mixture is heated in a rotary reactor to dehalogenate and partially volatilize the contaminants.
Glycolate Dehalogenation	An alkaline polyethylene glycol (APEG) reagent is used to dehalogenate halogenated aromatic compounds in a batch reactor. Potassium polyethylene glycol (KPEG) is the most common APEG reagent. Contaminated soils and the reagent are mixed and heated in a treatment vessel. In the APEG process, the reaction causes the polyethylene glycol to replace halogen molecules and render the compound non-hazardous. For example, the reaction between chlorinated organics and KPEG causes replacement of a chlorine molecule and results in a reduction in toxicity.
Soil Washing	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.
Soil Vapor Extraction	A vacuum is applied to a network of aboveground piping to encourage volatilization of organics from the excavated media. The process includes a system for handling off-gases.
Solidification/ Stabilization	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).
Solvent Extraction	Waste and solvent are mixed in an extractor, dissolving the organic contaminant into the solvent. The extracted organics and solvent are then placed in a separator, where the contaminants and solvent are separated for treatment and further use.

TABLE 3-3
DEFINITION OF MATRIX TREATMENT TECHNOLOGIES (CONTINUED)

Technology	Description
Ex Situ Thermal Treatment (assuming excavation)	
High-Temperature Thermal Desorption	Wastes are heated to 315-538 ?C (600-1,000 ?F) to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.
Hot Gas Decontamination	The process involves raising the temperature of the contaminated equipment or material for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants.
Incineration	High temperatures, 871-1,204 ?C (1,600- 2,200 ?F), are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.
Low-Temperature Thermal Desorption	Wastes are heated to 93-315 ?C (200-600 ?F) to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.
Open Burn/Open Detonation (OB/OD)	In OB operations, explosives or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as flame, heat, or a detonatable wave (that does not result in a detonation). In OD operations, detonatable explosives and munitions are destroyed by a detonation, which is initiated by the detonation of a disposal charge.
Pyrolysis	Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.
Vitrification	Contaminated soils and sludges are melted at high temperature to form a glass and crystalline structure with very low leaching characteristics.
Other Treatment	
Excavation and Off-Site Disposal	Contaminated material is removed and transported to permitted off-site treatment and disposal facilities. Pretreatment may be required.
Natural Attenuation	Natural subsurface processes—such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials—are allowed to reduce contaminant concentrations to acceptable levels.
GROUNDWATER, SURFACE WATER, AND LEACHATE	
In Situ Biological Treatment	
Co-Metabolic Processes	An emerging application involves the injection of water containing dissolved methane and oxygen into groundwater to enhance methanotrophic biological degradation.
Nitrate Enhancement	Nitrate is circulated throughout groundwater contamination zones as an alternative electron acceptor for biological oxidation of organic contaminants by microbes.
Oxygen Enhancement with Air Sparging	Air is injected under pressure below the water table to increase groundwater oxygen concentrations and enhance the rate of biological degradation of organic contaminants by naturally occurring microbes.
Oxygen Enhancement with Hydrogen Peroxide	A dilute solution of hydrogen peroxide is circulated throughout a contaminated groundwater zone to increase the oxygen content of groundwater and enhance the rate of aerobic biodegradation of organic contaminants by microbes.

TABLE 3-3
DEFINITION OF MATRIX TREATMENT TECHNOLOGIES (CONTINUED)

Technology	Description
In Situ Physical/Chemical Treatment	
Air Sparging	Air is injected into saturated matrices to remove contaminants through volatilization.
Directional Wells (enhancement)	Drilling techniques are used to position wells horizontally, or at an angle, in order to reach contaminants not accessible via direct vertical drilling.
Dual Phase Extraction	A high vacuum system is applied to simultaneously remove liquid and gas from low permeability or heterogeneous formations.
Free Product Recovery	Undissolved liquid-phase organics are removed from subsurface formations, either by active methods (e.g., pumping) or a passive collection system.
Hot Water or Steam Flushing/Stripping	Steam is forced into an aquifer through injection wells to vaporize volatile and semivolatile contaminants. Vaporized components rise to the unsaturated zone where they are removed by vacuum extraction and then treated.
Hydrofracturing (enhancement)	Injection of pressurized water through wells cracks low permeability and over-consolidated sediments. Cracks are filled with porous media that serve as avenues for bioremediation or to improve pumping efficiency.
Passive Treatment Walls	These barriers allow the passage of water while prohibiting the movement of contaminants by employing such agents as chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and others.
Slurry Walls	These subsurface barriers consist of vertically excavated trenches filled with slurry. The slurry, usually a mixture of bentonite and water, hydraulically shores the trench to prevent collapse and retards groundwater flow.
Vacuum Vapor Extraction	Air is injected into a well, lifting contaminated groundwater in the well and allowing additional groundwater flow into the well. Once inside the well, some of the VOCs in the contaminated groundwater are transferred from the water to air bubbles, which rise and are collected at the top of the well by vapor extraction.
Ex Situ Biological Treatment (assuming pumping)	
Bioreactors	Contaminants in extracted groundwater are put into contact with microorganisms in attached or suspended growth biological reactors. In suspended systems, such as activated sludge, contaminated groundwater is circulated in an aeration basin. In attached systems, such as rotating biological contractors and trickling filters, microorganisms are established on an inert support matrix.
Ex Situ Physical/Chemical Treatment (assuming pumping)	
Air Stripping	Volatile organics are partitioned from groundwater by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.
Filtration	Filtration isolates solid particles by running a fluid stream through a porous medium. The driving force is either gravity or a pressure differential across the filtration medium.
Ion Exchange	Ion exchange removes ions from the aqueous phase by exchange with innocuous ions on the exchange medium.
Liquid Phase Carbon Adsorption	Groundwater is pumped through a series of canisters or columns containing activated carbon to which dissolved organic contaminants adsorb. Periodic replacement or regeneration of saturated carbon is required.

TABLE 3-3
DEFINITION OF MATRIX TREATMENT TECHNOLOGIES (CONTINUED)

Technology	Description
Ex Situ Physical/Chemical Treatment (assuming pumping) (continued)	
Precipitation	This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. The process usually uses pH adjustment, addition of a chemical precipitant, and flocculation.
UV Oxidation	Ultraviolet (UV) radiation, ozone, and/or hydrogen peroxide are used to destroy organic contaminants as water flows into a treatment tank. An ozone destruction unit is used to treat off-gases from the treatment tank.
Other Treatment	
Natural Attenuation	Natural subsurface processes—such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials—are allowed to reduce contaminant concentrations to acceptable levels.
AIR EMISSIONS/OFF-GAS TREATMENT	
Biofiltration	Vapor-phase organic contaminants are pumped through a soil bed and sorb to the soil surface where they are degraded by microorganisms in the soil.
High Energy Corona	The HEC process uses high-voltage electricity to destroy VOCs at room temperature.
Membrane Separation	This organic vapor/air separation technology involves the preferential transport of organic vapors through a nonporous gas separation membrane (a diffusion process analogous to putting hot oil on a piece of waxed paper).
Oxidation	Organic contaminants are destroyed in a high temperature 1,000 ?C (1,832 ?F) combustor. Trace organics in contaminated air streams are destroyed at lower temperatures, 450 ?C (842 ?F), than conventional combustion by passing the mixture through a catalyst.
Vapor Phase Carbon Adsorption	Off-gases are pumped through a series of canisters or columns containing activated carbon to which organic contaminants adsorb. Periodic replacement or regeneration of saturated carbon is required.

✍ 3.1 IN SITU BIOLOGICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

The main advantage of in situ treatment is that it allows soil to be treated without being excavated and transported, resulting in potentially significant cost savings. However, in situ treatment generally requires longer time periods, and there is less certainty about the uniformity of treatment because of the variability in soil and aquifer characteristics and because the efficacy of the process is more difficult to verify.

Bioremediation techniques are destruction techniques directed toward stimulating the microorganisms to grow and use the contaminants as a food and energy source by creating a favorable environment for the microorganisms. Generally, this means providing some combination of oxygen, nutrients, and moisture, and controlling the temperature and pH. Sometimes, microorganisms adapted for degradation of the specific contaminants are applied to enhance the process.

Biological processes are typically easily implemented at low cost. Contaminants can be destroyed, and often little to no residual treatment is required; however, the process requires more time, and it is difficult to determine whether contaminants have been destroyed. Biological treatment of PAHs leaves less degradable PAHs (cPAHs) behind. These higher molecular weight cPAHs are classified as carcinogens. Also, an increase in chlorine concentration leads to a decrease in biodegradability. Some compounds, however, may be broken down into more toxic by-products during the bioremediation process (e.g., TCE to vinyl chloride). In in situ applications, these by-products may be mobilized to groundwater or contacted directly if no control techniques are used. This type of treatment scheme requires soil, aquifer, and contaminant characterization, and may require extracted groundwater treatment. Groundwater with low level contamination may sometimes be recirculated through the treatment area to supply water to the treatment area.

Although not all organic compounds are amenable to biodegradation, bioremediation techniques have been successfully used to remediate soils, sludges, and groundwater contaminated by petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Bioremediation is not applicable for treatment of inorganic contaminants.

The rate at which microorganisms degrade contaminants is influenced by the specific contaminants present, oxygen supply, moisture, temperature, pH, nutrient supply, bioaugmentation, and cometabolism. Treatability studies are typically conducted to determine the effectiveness of bioremediation in a given situation. These parameters are discussed briefly in the following paragraphs.

Oxygen level in the soil is increased by avoiding saturation of the soil with water, the presence of sandy and loamy soil as opposed to clay soil, avoiding compaction, avoiding high redox potential, and low concentrations of degradable materials. To ensure that oxygen is supplied at a rate sufficient to maintain aerobic conditions, forced air or hydrogen peroxide injection can be used. The use of hydrogen

peroxide is limited because at high concentrations (above 100 ppm, 1,000 ppm with proper acclimation), it is toxic to microorganisms. Also, hydrogen peroxide tends to decompose into water and oxygen rapidly in the presence of some soil constituents.

Anaerobic conditions may be used to degrade highly chlorinated contaminants, although at a very slow rate. This can be followed by aerobic treatment to complete biodegradation of the partially dechlorinated compounds as well as the other contaminants.

Water serves as the transport medium through which nutrients and organic constituents pass into the microbial cell and metabolic waste products pass out of the cell. Too much water can be detrimental, however, because it may inhibit the passage of oxygen through the soil (unless anaerobic conditions are desired).

Nutrients required for cell growth are nitrogen, phosphorous, potassium, sulfur, magnesium, calcium, manganese, iron, zinc, copper, and trace elements. If nutrients are not available in sufficient amounts, microbial activity will become limited. Nitrogen and phosphorous are the nutrients most likely to be deficient in the contaminated environment. These are usually added to the bioremediation system in a useable form (e.g., as ammonium for nitrogen and as phosphate for phosphorous). Phosphates can cause soil plugging as a result of their reaction with minerals, such as iron and calcium, to form stable precipitates that fill the pores in the soil and aquifer.

pH affects the solubility, and consequently the availability, of many constituents of soil, which can affect biological activity. Many metals that are potentially toxic to microorganisms are insoluble at elevated pH; therefore, elevating the pH of the treatment system can reduce the risk of poisoning the microorganisms.

Temperature affects microbial activity in the environment. The biodegradation rate will slow with decreasing temperature; thus, in northern climates bioremediation may be ineffective during part of the year unless it is carried out in a climate-controlled facility. The microorganisms remain viable at temperatures below freezing and will resume activity when the temperature rises.

Heating the bioremediation site, such as by use of warm air injection, may speed up the remediation process. At Eielson AFB, Alaska, passive solar warming by incubation tanks (ex situ) or the application of heated water below the ground surface to the contaminated vadose zone is being investigated. Too high a temperature can be detrimental to some microorganisms, essentially sterilizing the soil.

Temperature also affects nonbiological losses of contaminants mainly through the increased volatilization of contaminants at high temperatures. The solubility of contaminants typically increases with increasing temperature; however, some hydrocarbons are more soluble at low temperatures than at high temperatures. Additionally, oxygen solubility decreases with increasing temperature.

Bioaugmentation involves the use of microbial cultures that have been specially bred for degradation of specific contaminants or contaminant groups and sometimes for survival under unusually severe environmental conditions. Sometimes microorganisms from the remediation site are collected, separately cultured, and returned to the site as a means of rapidly increasing the microorganism population at the site. Usually an attempt is made to isolate and accelerate the growth of the population of natural microorganisms that preferentially feed on the contaminants at the site. In some situations different microorganisms may be added at different stages of the remediation process because the contaminants in abundance change as the degradation proceeds. USAF research, however, has found no evidence that the use of non-native microorganisms is beneficial in the situations tested.

Cometabolism uses microorganisms growing on one compound to produce an enzyme that chemically transforms another compound on which they cannot grow.

Treatability or feasibility studies are used to determine whether bioremediation would be effective in a given situation. The extent of the study can vary depending on the nature of the contaminants and the characteristics of the site. For sites contaminated with common petroleum hydrocarbons (e.g., gasoline and/or other readily degradable compounds), it is usually sufficient to examine representative samples for the presence and level of an indigenous population of microbes, nutrient levels, presence of microbial toxicants, and soil characteristics such as pH, porosity, and moisture.

Statistical characterization techniques should be used to represent "before" and "after" situations to verify biological treatment effectiveness.

Available in situ biological treatment technologies include biodegradation, bioventing, and white rot fungus. These technologies are discussed in Section 4 (Treatment Technology Profiles 4.1 through 4.3). Completed in situ biological treatment projects for soil, sediment, and sludge are shown in Table 3-4.

In situ biological treatment technologies are sensitive to certain soil parameters. For example, the presence of clay or humic materials in soil cause variations in biological treatment process performance.

TABLE 3-4
COMPLETED PROJECTS: IN SITU BIOLOGICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Remedial Action Seymour Recycling, IN Summer 1990 8/86 to 10/86 1/87 to 2/87 Jeff Gore (312) 886-6552	In situ soil bioremediation/ ABB Environmental Services	Soil (12 acres to 10 ft deep, approximately 43,500 yd^3)	54 contaminants present, including TCE, TCA, and carbon tetrachloride No standards or criteria for this OU in ROD	Additives - nitrogen, phosphorus, potassium, sulfur as fertilizer (200,000 gallons of nutrients added)	Tilling	Capping in
EPA Removal Action Roseville Drums, CA 2/12/88 to 11/9/88 Brad Shipley (415) 744-2287	In situ bioremediation/ EPA removal contractor	Soil (14 yd^3)	Input: Dichlorobenzene- 4,000 ppm Phenol - 12,000 ppm	Additives to soil: manure, water	Tilling	Output: Dichlorober 140 ppm Phenol - 6 p
EPA Removal Action Gila River Indian Reservation, AZ 6/24/85 to 10/23/85 Richard Martin (414) 744-2288	In situ anaerobic biological treatment (preceded by chemical treatment)/ EPA removal contractor	Soil (3,220 yd^3)	Toxaphene Input: 470 ppm Output: 180 ppm	pH: 8.3 to 9.8 Additives to soil: sulfuric acid, manure, sludge	Tilling	Capped in p

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TABLE 3-4
COMPLETED PROJECTS: IN SITU BIOLOGICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTIN

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Removal Action Gila River, Indian Reservation, AZ 3/28/85 to 6/24/85 Richard Martin (414) 744-2288	In situ chemical treatment (followed by anaerobic bioremediation)/ EPA removal contractor	Soil (3,200 yd^3)	Input: Toxaphene- 1,470 ppm Ethyl parathion- 86 ppm Methyl parathion- 24 ppm	pH: 10.12 to 11.8 Moisture: wet Additives to soil: sodium hydroxide, water	Bioremediation	Output: Toxaphene ppm Ethyl parath ppm Methyl para ppm
Navy Demo Naval Communication Station, Scotland 2/85 to 10/85 Deh Bin Chan (805) 982-4191	Biodecontamination of fuel oil spills	Soil	Fuel Oil	In situ; microorganisms function best at 20-35 ?C	In situ	In situ
DOE Savannah River Site, SC Terry C. Hazen (803) 725-5178	Biodegradation	Soil & ground-water	TCE, PCE declined to <2 ppb	In situ	Injection of 1- 4% methane/air into aquifer via horizontal wells	In situ
Army Demo U.S. Army Construction Engineering Research Laboratory, IL Jean Donnelly (217) 352-6511	Biodegradation of lube oil-contaminated soils	Soil	Motor oil/lubrication oil	In situ.	Disk inoculant & nutrients into contaminated soil. Cover soil w/ventilated plastic sheeting.	In situ
Air Force Demo Kelly AFB, TX & Eglin AFB, FL Joe Laird	In situ Biodegradation	Soil & ground-water	Hydrocarbons- fuels, fuel oils, & non-halogenated solvents	In situ – soil conditioning and electron acceptor addition.	Nutrients introduced into aquifer through irrigation wells	Pumping we remove exc

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TABLE 3-4
COMPLETED PROJECTS: IN SITU BIOLOGICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTIN

Site Name/Contact	Technology/Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Residu Manage
DOE Demo Savannah River Site, SC Nate Ellis (803) 952-4846 Brian Loony (803) 752-5181	Vegetation-enhanced biodegradation	Soil	TCE, PCE & PAHs at 10,000 ppb	In situ	Root-associated micro-organisms degrade contaminants.	In situ
Air Force Tech Demo - Program was launched in 5/92 Lt. Col. Ross N. Miller (210) 536-4331	Bioventing initiative	Soil	Diesel, jet fuel, fuel oil, or petroleum hydrocarbons	Aerobic degradation by direct injection or extraction of air	Temporary shutdown of air injection in vent well to measure in situ rate of oxygen res-piration in the monitoring wells.	In situ techn non- and se volatile hyd
DOI Tech Demo (USGS) Galloway Township, NJ 1988 Herbert T. Buxton (609) 771-3900	Vapor extraction and bioventing design	Soil & ground-water	Gasoline	AIRFLOW - an adaptation of the USGS groundwater flow simulator	MODFLOW to perform airflow simulations to predict well locations and pumping rates	None

Sources: *Innovative Treatment Technologies: Annual Status Report* (EPA, 1993).
Synopsis of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

✍ 3.2 IN SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

The main advantage of in situ treatment is that it allows soil to be treated without being excavated and transported, resulting in potentially significant cost savings. However, in situ treatment generally requires longer time periods, and there is less certainty about the uniformity of treatment because of the variability in soil and aquifer characteristics and because the efficacy of the process is more difficult to verify.

Physical/chemical treatment uses the physical properties of the contaminants or the contaminated medium to destroy (i.e., chemically convert), separate, or contain the contamination. Soil vapor extraction uses the contaminant's volatility to separate it from the soil. Soil flushing uses the contaminant's solubility in liquid to physically separate it from the soil. Surfactants may be added to the flushing solution to chemically increase the solubility of a contaminant. Solidification/stabilization also uses both physical and chemical means. Solidification encapsulates the contaminant, while stabilization physically alters or binds with the contaminant. Pneumatic fracturing is an enhanced technique that physically alters the contaminated media's permeability by injecting pressurized air to develop cracks in consolidated materials.

Physical/chemical treatment is typically cost effective and can be completed in short time periods (in comparison with biological treatment). Equipment is readily available and is not engineering or energy-intensive. Treatment residuals from separation techniques will require treatment or disposal, which will add to the total project costs and may require permits. Extraction fluids from soil flushing will increase the mobility of the contaminants, so provisions must be made for subsurface recovery.

Available in situ physical/chemical treatment technologies include soil vapor extraction, soil flushing, solidification/stabilization, and pneumatic fracturing. These treatment technologies are discussed in Section 4 (Treatment Technology Profiles 4.4 through 4.7). Completed in situ physical/chemical treatment projects for soil, sediment, and sludge are shown in Table 3-5.

Certain in situ physical/chemical treatment technologies are sensitive to certain soil parameters. For example, the presence of clay or humic materials in soil causes variations in horizontal and vertical hydraulic parameters, which, in turn, cause variations in physical/chemical process performance. Stabilization/solidification technologies are less sensitive to soil parameters than other physical/chemical treatment technologies.

TABLE 3-5
COMPLETED PROJECTS: IN SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Remedial Action Sacramento AD Tank 2 OU, CA 11/91 to 4/93 Marlin Mezquita (415) 744-2393 George Siller (916) 557-7418 Dan Oburn (916) 388-4344	In situ SVE/ Terra Vac, Inc., Costa Mesa, CA	Soil (150 yd^3)	Initial concentration: MEK 15 ppm Ethylbenzene 2,100 ppm PCE 39 ppm Total xylene 11,000 ppm Cleanup goal: 1.2 ppm MEK 6 ppm Ethylbenzene 23 ppm total xylene 0.2 ppm PCE	24 hours/day	None	Extracted va treated with phase carbo adsorption. Entrained (suspended treatment by existing on-s hydrogen pe treatment pl
EPA Remedial Action Fair Child Semiconductor San Jose, CA 1989 to 6/90 Helen McKinley (510) 744-2236 Steve Hill (510) 286-0433	SVE with air flushing	Soil (2,000,000 yd^3)	Initial concentration: TCA 670,000 ppb 1,1-DCE 6,400 ppb Freon 113 7,200 ppb Final concentrations unknown Target was 1 ppm	In situ	Excavation dewatering of soil where leaking UST was discovered	Carbon can stripping for and treat
EPA Remedial Action Hollingsworth Solderless, FL 1/91 to 7/91 John Zimmerman (404) 347-2643	SVE/EBASCO	Soil (60 yd^3, down to 7 feet deep)	TCE, vinyl chloride Target: total VOCs 1 ppm	In situ	None required	Air emission to atmosphe

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TABLE 3-5
COMPLETED PROJECTS: IN SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Remedial Action Verona Wellfield (Thomas Solvent/Raymond Road), MI 3/88 to 5/92 Margaret Guerriero (312) 886-0399	SVE (attempted nitrogen sparging)/ Terra Vac, Inc. Costa Mesa, CA	Soil (35,000 yd^3, ½ acre to 18 ft deep)	Initial soil concentration: TCE 550,000 ppb PCE 1.8 million ppb Toluene 730,000 ppb Xylene 500,000 ppb Criteria in all post remedial soil samples: TCE 60 ppb PCE 10 ppb Toluene 15,000 ppb Total xylenes 6,000 ppb	60 - 160 ft^3/min of air Started >4,400 lb/day removed Shut off 6 lb/day removed Total removed 65,000 lb	No materials handling; required installing extraction wells	Spent carbo regenerated eventually incinerated)
EPA Remedial Action Rocky Mountain Arsenal (OU 18) Interim Response, CO 6/91 to 12/91 Stacey Eriksen (303) 294-1083	SVE/Woodward Clyde Denver, CO	Soil (100 ft radius down to 60 ft; approximately 70,000 yd^3)	TCE Initial extracted gas concentration 60 ppm Final extracted gas concentration 2 to 3 ppm	250 to 300 ft^3/ min. of air Total removed 64 lb	Required installing extraction wells	Vapor phas adsorption

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TABLE 3-5
COMPLETED PROJECTS: IN SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Removal Action Hinson Chemical, SC 12/88 to 3/92 Fred Stroud (404) 347-3136	SVE/OH Materials Atlanta, GA	Soil (60,000 yd^3, up to 50 ft deep)	Benzene, TCE, PCE, DCA, MEK At completion: <10 ppm Total VOCs (in all samples); average <1 ppm Total VOCs	In situ; continuous operation (except for occasional shut downs to allow soil gas to reach equilibrium in the pore spaces)	No cap needed	Air emissior captured or phase carb
EPA Removal Action CSX McCormick Derailment Site, SC Steve Spurlin (404) 347-3931	SVE with air flushing/MWRI	Soil (200,000 yd^3)	BTEX 130,000-gallon spill	Used a system of extraction and injection wells. 1,000 separate PVC wells. Injection wells 7 to 8 feet deep. Extraction wells 2 to 3 feet deep.	Brought in clay to cover the area, to prevent air from infiltrating	Wastewater site for treat Vapors cap put through out pot and incinerated.

TABLE 3-5
COMPLETED PROJECTS: IN SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Luke AFB, AZ 11/91 to 5/92 Jerome Stolinsky (402) 221-7170 Dan McCafferty (406) 523-1150	SVE with air flushing and thermal oxidation of off-gases/Jacobs Engineering	Soil (35,000 yd^3)	VOCs (2-hexanone, 2-butanone, 4-methyl 2 pentanone, BTEX)	In situ down to 100 ft	Removed approximately 11,000 lb of vapors and 4,000 lb of condensate	Off gas vap thermally ox
EPA Demo Douglassville, PA 10/87 Paul R. dePercin (513) 569-7797 Ray Funderburk (903) 545-2002	Chemical treatment & immobilization	Soil & sludge	Organic compounds, heavy metals, oil, & grease	In/ex situ. Sediments-- underwater. Batch process at 120 tons/hour	Blending with cement or fly ash, water, and "Chloranan"	Treated ma hardens to concrete-lik
DOE Demo Savannah River Site, SC 7/90 to 12/90 Brian Loony (803) 725-5181	In situ air stripping with horizontal wells	Soil & ground-water	TCE & PCE initial concentrations: 5000 ppm; stabilized to 200-300 ppm	In situ (horizontal wells)	One well below water table injects air while shallower well draws vacuum.	Extraction a 110 lb of VO

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TABLE 3-5
COMPLETED PROJECTS: IN SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Air Force & EPA Demo McClellan AFB, CA 2/93 Joseph Danko (503) 752-4271	In situ SVE	Vadose zone soils only	VOCs: TCE, DCE, vinyl chloride, toluene, xylene, & chlorobenzenes in the 100-1,000 ppm range	Vacuum required to pull contaminants to the surface	In situ	Contaminar treated with catalytic oxi unit prior to atmospheri
Air Force Demo Hill AFB, UT 12/88 to 10/89 Capt. E.G. Marchand (904) 283-6023	In situ soil venting	Unsaturated soils	Fuels and TCE. Fuel residual was <100 ppm	Venting rates varied from 250 to 1,000 ft^3/min	May be necessary to seal surface to air	Transfer-of-method, so is not destr
Army Demo Twin Cities AAP, MN 1986 to 1993 Eric Hangeland (410) 671-2054	In situ soil venting	Unsaturated soil	VOCs. Removed 400 lb of VOCs/day initially,down to 15 lb/day at end	System had 40 vents and 4 20-hp blowers. Vents averaged 30 ft in depth	May be necessary to seal surface to air	Off gas stre
EPA Demo Superfund Sites Puerto Rico & Massachusetts 1987 to 1988 Mary Stinson (908) 321-6683 James Malot (809) 723-9171	In situ vacuum extraction	Vadose or unsaturated zone soils	VOCs - gas, fuel, 1,300 lb VOC removed in 56 days, average reduction 90% (clay) to 92% (sand)	4 extraction wells, ideal permeability 10^{-4} to 10^{-8} cm/s, Henry's law >0.0001	Typically 20-2,500 lb/day of contaminant	Emission co required

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TABLE 3-5
COMPLETED PROJECTS: IN SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIME NT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Army Demo Luke AFB, AZ 1992 Jerome Stolinsky (402) 221-7170	SVE	Soil	BTEX (16, 183, 84, 336 ppm) and TRPH (1,300 ppm)	In situ - 2 60-ft extraction wells at 100 scfm	In situ	Carbon air t residual cor generated a and incinera
EPA Demo Buchanan, MI 1992 to 1993 Kim Lisa Kreiton (513) 569-7328 Gale Billings (505) 345-1116	Subsurface volatilization & ventilation system (SVVS)	Soil	Organics, fuels	O_2, CO^2, & microbes monitored	In situ	VOC emissi treated in bi required
DOE Demo LLNL, CA Mike Gill (415) 744-2383	Vacuum-induced soil venting	Unsaturated Soil	Gasoline - 99.8% destruction, 100 gal. free product removed	In situ - each well has 5 vents above water table, including 2 above 20-25 inches Hg, 60 ft^3/minute	Includes manually adjusted skimming pipe	Thermal oxi vapors - 99. destruction
Army Demo Sacramento Army Depot, CA 1992 to 1993 Ron Oburn (916) 388-4344 Bob Cox (Terra Vac)	Vapor extraction system	Soil - 200 yd^3	Ethylbenzene, butanone, xylene, PCE	In situ	To depth of 18 ft	Vapor treate thermal bur catalytic oxi Entrained w treated off-s

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TABLE 3-5
COMPLETED PROJECTS: IN SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Demo NJDEPE-ECRA Site, NJ 1992 Uwe Frank (908) 321-6626 John Liskowitz (908) 739-6444	Pneumatic Fracturing Extraction_ & Hot Gas Injection (HGI)	Soil & rock	VOCs, SVOCs	In situ - hot gas @ 200 ?F	Injection of compressed gas to fracture soil, HGI to strip contaminants	Off-gas flow increased, concentratio remained co
EPA *SITE* Demo Hialeah, FL 1988-90 Mary Stinson (908) 321-6683	In situ solidification and stabilization	Wet or dry soil, sludge, sediment	PCBs, inorganic and organic cpds	Slurry injection with auger rotating at 15 rpm	Mixing, binding agent is modified for each waste	PCB immob is likely but confirmed
EPA Demo Oak Brook, IL & Dayton, OH 1991 Naomi Barkley (513) 569-7854 Larry Murdock (513) 569-7897	Hydraulic fracturing	Soil	Rate of bioremediation increased 75% for BTEX, 77% for TPH	In situ	Water infiltration into vapor extraction area should be prevented	Fracture gro measured th the deforma the ground

Sources: *Innovative Treatment Technologies: Annual Status Report* (EPA, 1993).
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

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✍ 3.3 IN SITU THERMAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

The main advantage of in situ treatment is that it allows soil to be treated without being excavated and transported, resulting in significant cost savings. However, in situ treatment generally requires longer time periods, and there is less certainty about the uniformity of treatment because of the variability in soil and aquifer characteristics and because the efficacy of the process is more difficult to verify.

Thermal treatment offers quick cleanup times, but it is generally the most costly treatment group. Cost is driven by energy and equipment costs and is both capital and O&M-intensive.

Thermally enhanced SVE is an extraction technique that uses temperature to increase the volatility of the contaminants in the soils. Thermally enhanced SVE may require off-gas and/or residual liquid treatment. In situ vitrification uses heat to melt soil, destroying some organic compounds and encapsulating inorganics.

Available in situ thermal treatment technologies include thermally enhanced SVE and vitrification. These technologies are discussed in Section 4 (Treatment Technology Profiles 4.8 and 4.9). Completed in situ thermal treatment projects for soil, sediment, and sludge are shown in Table 3-6.

TABLE 3-6
COMPLETED PROJECTS: IN SITU THERMAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
DOE Demo LLNL, CA 1993 Roger D. Aines, Robin L. Newmark (415) 423-7184 or 3644	Dynamic underground stripping	Concentrated underground plumes	Organics	In situ injection pressure controlled to increase with depth	Combination of steam injection and 3-phase soil heating	Organics vo and extracte vapor strea
EPA Demo Geosafe Test Site, WA; Hanford Nuclear Reservation, WA, ORNL, TN; INEL, ID 1993 Teri Richardson (513) 569-7949 James Hanson (206) 822-4000	In situ vitrification	Soil & sludge	Organics & inorganics	1,600-2,000?C Transmission voltages=12.5 or 13.8 kV	In situ	Off-gas trea system rem pollutants (I quenching, scrubbing, I filtration)
DOE Demo Hanford Reservation, WA; ORNL, TN 1993 Leo E. Thompson (509) 376-5150 James E. Hansen (509) 375-0710	In situ vitrification	Soils	Organics, inorganics, & radionuclides	Joule heating through electrodes	In situ	Organics de inorganics incorporate resultant ma

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TABLE 3-6
COMPLETED PROJECTS: IN SITU THERMAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTINUE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Air Force Demo Volk Field ANGB, WI 1985, 1989, 1993 Paul F. Carpenter (904) 523-6022	Radio frequency (RF) thermal soil decontamination	Soils	Solvents & volatile & semivolatile petroleum hydro-carbons 94-99% decontamination in 12 days	Power source is 45 kW electric-magnetic generator	Heating, volatilization	Off gas cap surface or t electrodes
DOE Demo Hanford Reservation, WA 10/93 W.O. Heath, T.M. Bergsman (509) 376-0554 or 3638	Six-phase soil heating	Soils	VOCs	In situ Resistive heating	6 electrodes placed around central extraction vent	Off-gases n treated befo release
DOE Demo Sandia National Laboratory, NM Fall 1993 Darrel Bandy (505) 845-6100 James M. Phelan (505) 845-9892	Thermally enhanced vapor extraction	Soils	VOCs	In situ Voltages: 200-1,600V Temp: 100 ?C	Resistive heating & radio frequency heating	Off gas mus treated
EPA Demo Annex Terminal, San Pedro, CA 1989 Paul DePercin (513) 569-7797	In situ steam & air stripping	Soil	VOCs and SVOCs. Up to 55% SVOC removal; >85% VOC removal	Treatment rate of 3 yd^3/hr. Steam 450 ?F 450 psig. Transportable treatment unit includes off-gas shroud & auger injection/extraction wells.	Can also be used to treat soil w/injection of reactive chemicals	Water and a with carbon water recyc process.

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TABLE 3-6
COMPLETED PROJECTS: IN SITU THERMAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTINUE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Demo LeMoore NAS, CA 1988 Paul DePercin (513) 569-7797	In situ steam-enhanced extraction (SEE)	Soils above and below the water table	VOCs and SVOCs; recovery 10x greater than w/ vacuum extraction alone	Steam injected into soil	Gasoline recovery reduces treatment required at surface	Recovered contaminan either conde treated with air or liquid
EPA Demo San Fernando Valley Groundwater Basin Superfund Site, CA 1990 Norma Lewis (513) 569-7665	Integrated Vapor Extraction & Steam Vacuum Stripping	Soil & Ground-water	Organics - up to 2.2 ppm TCE up to 11 ppm PCE Up to 99.99% removal	In situ Groundwater 1,200 gpm Soil gas 300 ft/min	Groundwater steam stripping tower and SVE of soil	Carbon sho regenerated hours
EPA Demo Huntington Beach, CA 1993 Paul DePercin (513) 569-7797	Steam Enhanced Recovery Process (SERP)	Soils	Diesel fuel spill	In situ	Steam injection	NAPLs sepa gravity wate treatment
EPA Demo Pennsylvania Power and Light, PA 1993 Eugene Harris (513) 569-7862	Contained Recovery of Oily Wastes (CROW?)	Soil	Oily wastes - NAPLs, coal tar, PCP creosote, petroleum hydrocarbons	In situ	Steam/hot water displacement	Oily waste b surface
Air Force & EPA Demo Kelly AFB, TX Reinaldo Matias (513) 569-7149	HRUBOUT® Process	Soils	VOCs & SVOCs	In situ. Operates 24 hours/day. Hydrocarbons destroyed at 1,500 ?F	Heated air injected below contamination.	Vapors to th oxider

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Sources: *Innovative Treatment Technologies: Annual Status Report*(EPA, 1993).
Synopses of Federal Demonstrations of Innovative SiteRemediation Technologies(FRTR, 1993).

✍ 3.4 EX SITU BIOLOGICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

The main advantage of ex situ treatment is that it generally requires shorter time periods than in situ treatment, and there is more certainty about the uniformity of treatment because of the ability to homogenize, screen, and continuously mix the soil. However, ex situ treatment requires excavation of soils, leading to increased costs and engineering for equipment, possible permitting, and material handling/worker exposure considerations.

Bioremediation techniques are destruction or transformation techniques directed toward stimulating the microorganisms to grow and use the contaminants as a food and energy source by creating a favorable environmental for the microorganisms. Generally, this means providing some combination of oxygen, nutrients, and moisture, and controlling the temperature and pH. Sometimes, microorganisms adapted for degradation of the specific contaminants are applied to enhance the process.

Biological processes are typically easily implemented at low cost. Contaminants can be destroyed or transformed, and little to no residual treatment is required; however, the process requires more time and difficult to determine whether contaminants have been destroyed. Biological treatment of PAHs leaves less degradable PAHs (cPAHs) behind. These higher molecular cPAHs are classified as carcinogens. Also, an increase in chlorine concentration leads to a decrease in biodegradability. Some compounds, however, may be broken down into more toxic by-products during the bioremediation process (e.g., TCE to vinyl chloride). An advantage over the in situ applications is that in ex situ applications, these by-products are contained in the treatment unit until nonhazardous end-products are produced.

Although not all organic compounds are amenable to biodegradation, bioremediation techniques have been successfully used to remediate soils, sludges, and groundwater contaminated by petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Bioremediation is not generally applicable for treatment of inorganic contaminants.

The rate at which microorganisms degrade contaminants is influenced by the specific contaminants present; oxygen supply; moisture; nutrient supply; pH; temperature; the availability of the contaminant to the microorganism (clay soils can adsorb contaminants making them unavailable to the microorganisms); the concentration of the contaminants (high concentrations may be toxic to the microorganism); the presence of substances toxic to the microorganism, e.g., mercury; or inhibitors to the metabolism of the contaminant. These parameters are discussed briefly in the following paragraphs.

Oxygen level in ex situ applications is easier to control than in in situ applications and is typically maintained by mechanical tilling, venting, or sparging.

Anaerobic conditions may be used to degrade highly chlorinated contaminants.

This can be followed by aerobic treatment to complete biodegradation of the partially dechlorinated compounds as well as the other contaminants.

Water serves as the transport medium through which nutrients and organic constituents pass into the microbial cell and metabolic waste products pass out of the cell. Moisture levels in the range of 20% to 80% generally allow suitable biodegradation in soils.

Nutrients required for cell growth are nitrogen, phosphorous, potassium, sulfur, magnesium, calcium, manganese, iron, zinc, and copper. If nutrients are not available in sufficient amounts, microbial activity will stop. Nitrogen and phosphorous are the nutrients most likely to be deficient in the contaminated environment and thus are usually added to the bioremediation system in a useable form (e.g., as ammonium for nitrogen and as phosphate for phosphorous).

pH affects the solubility, and consequently the availability, of many constituents of soil, which can affect biological activity. Many metals that are potentially toxic to microorganisms are insoluble at elevated pH; therefore, elevating the pH of the treatment system can reduce the risk of poisoning the microorganisms.

Temperature affects microbial activity in the treatment unit. The biodegradation rate will slow with decreasing temperature; thus, in northern climates bioremediation may be ineffective during part of the year unless it is carried out in a climate-controlled facility. The microorganisms remain viable at temperatures below freezing and will resume activity when the temperature rises. Too high a temperature can be detrimental to some microorganisms, essentially sterilizing the soil. Compost piles require periodic tilling to release self -generated heat.

Temperature also affects nonbiological losses of contaminants mainly through the volatilization of contaminants at high temperatures. The solubility of contaminants typically increases with increasing temperature; however, some hydrocarbons are more soluble at low temperatures than at high temperatures. Additionally, oxygen solubility decreases with increasing temperature. Temperature is more easily controlled ex situ than in situ.

Bioaugmentation involves the use of cultures that have been specially bred for degradation of a variety of contaminants and sometimes for survival under unusually severe environmental conditions. Sometimes microorganisms from the remediation site are collected, separately cultured, and returned to the site as a means of rapidly increasing the microorganism population at the site. Usually an attempt is made to isolate and accelerate the growth of the population of natural microorganisms that preferentially feed on the contaminants at the site. In some situations different microorganisms may be added at different stages of the remediation process because the contaminants in abundance change as the degradation proceeds. USAF research, however, has found no evidence that the use of non-native microorganisms is beneficial in the situations tested.

Cometabolism, in which microorganisms growing on one compound produce an enzyme that chemically transforms another compound on which they cannot grow, has been observed to be useful. In particular, microorganisms that degrade methane (methanotrophic bacteria) have been found to produce enzymes that can initiate the oxidation of a variety of carbon compounds.

Treatability or feasibility studies are used to determine whether bioremediation would be effective in a given situation. The extent of the study can vary depending on the nature of the contaminants and the characteristics of the site. For sites contaminated with common petroleum hydrocarbons (e.g., gasoline and/or other readily degradable compounds), it is usually sufficient to examine representative samples for the presence and level of an indigenous population of microbes, nutrient levels, presence of microbial toxicants, and soil characteristics such as pH, porosity, and moisture.

Available ex situ biological treatment technologies include composting, controlled solid phase biological treatment, landfarming, and slurry phase biological treatment. These technologies are discussed in Section 4 (Treatment Technology Profiles 4.10 through 4.13). Completed ex situ biological treatment projects for soil, sediment, and sludge are shown in Table 3-7.

TABLE 3-7
COMPLETED PROJECTS: EX SITU BIOLOGICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Remedial Action Brown Wood Preserving, FL 10/88 to 12/91 Martha Berry (404) 347-2643	Land treatment/Remediation Technologies, Seattle, WA	Soil/pond sediment (7,500 yd^3)	Criteria: 100 ppm total carcinogenic PAHs as sampled on 8 subplots on each lift Input: 800 to 2,000 ppm total creosote contaminants Output: 10 to 80 ppm total carcinogenic indicators	Retention time- 3 to 6 months Additives - water and nutrients	Excavation Screening Tilling	Treated ma vegetated w (no cap)
EPA Removal Action Poly-Carb, Inc., NV 7/22/87 to 8/16/88 Bob Mandel (415) 744-2290	Land treatment and soil washing/EPA removal contractor	Soil (1,500 yd^3)	Input: Phenol - 1,020 ppm o-creosol - 100 ppm m- and p-creosol - 409 ppm Output: Phenol - 1 ppm o-creosol - 1 ppm m- and p-creosol - 0.92 ppm	Additives: water	Excavation Placement in double-lined pit Irrigation Tilling	Leachate co and treatme granular act carbon
EPA Removal Action Scott Lumber, MO 8/87 to Fall 1991 Bruce Morrison (913) 551-5014	Land treatment/ RETEC Chapel Hill, NC	Soil (16,000 yd^3)	Criteria: 500 ppm - Total PAH 14 ppm - Benzo(a)pyrene	Additives: Water Phosphates	Tilling	Output: 160 ppm To 12 ppm Benzo(a)py

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TABLE 3-7
COMPLETED PROJECTS: EX SITU BIOLOGICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTIN

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Matagorda Island Af Range, TX 10/92 to 2/28/93 Vic Heister (918) 669-7222	Ex situ bioremediation; solid phase. All constructed on abandoned runway. Bacteria added and mechanically mixed.	Soil (500 yd^3)	PAHs TPH - 3,400 ppm BTEX - 41.3 ppm Criteria: Texas Water Commission standards 100 ppm for TPH 30 ppm for BTEX	Batch process retention time: 3 months 9-inch layers treated Ambient temperature bacteria added to waste	Excavated approximately 40 by 60 ft area. Constructed on poly barrier and clean sand base. Did some mixing.	Backfilled th into the exc
Navy Marine Corps Mountain Warfare Center Bridgeport, CA 8/89 to 11/89 Diane Soderland (907) 753-3425 Bill Major (DOD) (805) 982-1808	Bioremediation (ex situ); heap pile bioreactor.	Soil (7,000 yd^3)	PAHs (petroleum hydrocarbons, diesel), metals (lead)	Temperature, pressure, and moisture content are monitored.	Excavation	After 20 mo operation, th levels were
Army Ft. Ord Marina, Fritzche AAF Fire Drill Area, CA Winter 1991 Gail Youngblood (408) 242-8017	Land treatment	Soil (4,000 yd^3)	TCE, MEK, TPH, BTEX	Initial concentration >1,000 ppm End concentration <200 ppm	Ex situ	None
Army Demo Louisiana Army Ammunition Plant, LA 12/87 to 4/88 Peter Marks (610) 701-3039 Capt. Kevin Keehan (410) 671-2054	Aerated static pile composting	Lagoon sediments	TNT, HMX, RDX Initial concentrations: 17000 mg/kg.	Thermophilic (55 ?C) and mesophilic (35 ?C). Add bulking agents: horse manure, alfalfa, straw, fertilizer, horse feed	Mixing	Final conce meso=376 m therm=74 m reductions: TNT=99.6/9 RDX=94.8/9 HMX=86.9/9

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TABLE 3-7
COMPLETED PROJECTS: EX SITU BIOLOGICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTIN

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Army Demo Badger Army Ammunition Plant, WI 4/88 to 1/89 Peter Marks (610) 701-3039 Capt. Kevin Keehan (410) 671-2054	Aerated static pile composting	Soil & sediments	Nitrocellulose reduction > 99.5%	Thermophilic (55?C) and mesophilic (35?C)	Mixing	Runoff colle from compo pads
Army Demo Umatilla Depot Activity, OR Harry Craig (503) 326-3689	Aerobic composting optimization	Soil & sediment (4,800 yd^3)	TNT, HMX, RDX	Maintain pH, temperature, moisture content, oxygen content	Mix with bulking agents & organic amendments	Runoff colle from compo pads
Navy Demo Naval Weapons Station Seal Beach, CA Steve McDonald (310) 594-7273 Carmen Lebron (805) 982-1615	Bioremediation of aromatic hydrocarbons – unleaded gasoline spill	Soil & groundwater	1 ppb to 4 ppm of BTEX	3 80-litre bioreactors at 72 L/day	Site soil placed in reactor – groundwater pumped through	Effluent clea drinking wa standards f
EPA *SITE* Demo Ronald Lewis (513) 569-7856 Merv Cooper (206) 624-9349	Liquids & solids biological treatment (LST)	Soils, sediments, & sludge	Biodegradable organics	Suspended solids up to 20%	Mixing & aeration	Managed by adsorption biofiltration

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TABLE 3-7
COMPLETED PROJECTS: EX SITU BIOLOGICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTIN

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA *SITE* Demo EPA Test & Evaluation Facility, OH 5/91 to 9/91 Ronald Lewis (513) 569-7856	Bioslurry reactor	Soils, sediments, & sludge	97% reduction in PAHs	Degradation enhanced by control of pH, temperature, oxygen, nutrients, and enriched indigenous microorganisms	Excavation, mixing, additives, sparging	—
Navy Demo Camp Pendleton, CA 1991 William Sancet (619) 725-3868	Enzyme catalyzed, accelerated biodegradation	Soil	TPH reduced from 29,000 ppm to 88 ppm (well below 100 ppm goal)	50 yd^3/month capacity	Soil tilled with a garden tractor after each product application and once each week	No residual produced. maintenanc required
Army Demo Joliet Army Ammunition Plant, IL 1992 Kevin Keehan (410) 671-2054	Soil slurry-sequencing batch bioreactor	Soil	TNT, RDX, HMX TNT reduced from 1,300 to 10 ppm	In tank or reactor	Excavation and pre-screening (to remove large debris)	Slurry remo dewatered; water recyc
EPA Demo Santa Maria, CA 5/92 Annette Gatchett (513) 569-7697	Biogenesis_ soil washing process	Soil	Organics - oils, fuels, PCBs, PAHs 85-99% removal of hydrocarbons with initial concentration up to 15,000 ppm	30-65 tons/hour	Agitation in unit with surfactant	Wash water oil/water se filter and bi

Sources: *Innovative Treatment Technologies: Annual Status Report* (EPA, 1993).
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

✍ 3.5 EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

The main advantage of ex situ treatment is that it generally requires shorter time periods than in situ treatment, and there is more certainty about the uniformity of treatment because of the ability to homogenize, screen, and continuously mix the soil. Ex situ treatment, however, requires excavation of soils, leading to increased costs and engineering for equipment, possible permitting, and material handling.

Physical/chemical treatment uses the physical properties of the contaminants or the contaminated medium to destroy (i.e, chemically convert), separate, or contain the contamination. Chemical reduction/oxidation and dehalogenation (BCD or glycolate) are destruction technologies. Soil washing, SVE, and solvent extraction are separation techniques, and S/S is an immobilization technique.

Physical/chemical treatment is typically cost effective and can be completed in short time periods (in comparison with biological treatment). Equipment is readily available and is not engineering or energy-intensive. Treatment residuals from separation techniques will require treatment or disposal, which will add to the total project costs and may require permits.

Available ex situ physical/chemical treatment technologies include chemical reduction/oxidation, dehalogenation (BCD or glycolate), soil washing, SVE, S/S, and solvent extraction. These technologies are discussed in Section 4 (Treatment Technology Profiles 4.14 through 4.20). Completed ex situ physical/chemical treatment projects for soil, sediment, and sludge are shown in Table 3-8.

TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Remedial Action Upjohn Manufacturing Company, PR 1/83 to 3/88 Alison Hess (212) 264-6040	SVE/Terra Vac, Inc., Costa Mesa, CA	Soil	Criteria: Initial concentrations - 70 ppm (carbon tetrachloride to air) Final concentrations - nondetect (<0.002 ppm)	Ambient conditions	Ex situ	Discharge c vapors thro stack
EPA Remedial Action Palmetto Wood Preserving, SC 9/28/88 to 2/8/89 McKenzie Mallary (404) 347-7791	Chemical treatment and soil washing; reduction of hexavalent chromium to trivalent chromium/En-site (ERCS contractor) Atlanta, GA	Soil (13,000 yd^3)	Input: Arsenic - 2 to 6,200 ppm Chromium - 4 to 6,200 ppm Output: Arsenic - less than 1 ppm Chromium - 627 ppm	Soil - Batch process Treatment for aqueous waste from soil washing - 25 gpm pH - 2 to 9	(1) Used sodium metaphosphate to lower pH to 2.0 and wash the chromium from the soil, (2) separated the soil and solution, (3) solidified the soils, and (4) used the ferrous ion method of reduction to precipitate the chromium from solution in trivalent form	Soil - solidif replaced on Wastewater permitted di to the sewe Sludge - off- disposal

TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Remedial Action Wide Beach Development, NY 9/90 to 9/91 Herb King (212) 264-1129	APEG dechlorination/ Soil Tech Denver, CO	Soil (40,000 yd^3)	Criteria: PCB - <10 ppm (1 composite sample/day) Input: 10 to 100 ppm PCB Output: 2 ppm PCB	Continuous process 8 tons/hour 200 to 580 ?C (450 to 1,100 ?F) Ambient pH and moisture Additives - Alkaline polyethylene glycol (APEG)	Excavation Screening Staging	Treated soil disposed of
EPA Removal Action Traband Warehouse PCBs, OK 2/90 to 9/90 Pat Hammack (214) 655-2270	Solvent extraction/Terra-Clean	Solids	PCBs Initial: 7,500 ppm	Solvent addition	Excavation	Treated soil concentrate contaminan
EPA Removal Action PBM Enterprises, MI 3/25/85 to 10/28/85 Ross Powers (312) 378-7661	Neutralization with hypochlorite process/Mid-American Environmental Service Riverdale, IL	Film chips (464 tons or 1,280 yd^3)	Cyanide Input: 200 ppm Output: 20 ppm	Time: 2 to 3 hours Additives: sodium hydroxide	Agitation	Rinse water and waste hypochlorite off-site Treated chi landfilled (S
EPA Removal Action Stanford Pesticide Site No. 1, AZ 3/20/87 to 11/4/87 Dan Shane (415) 744-2286	Chemical treatment - alkaline hydrolysis/EPA removal contractor	Soil (200 yd^3)	Methyl parathion Input: 24.2 ppm Output: 0.05 ppm	pH: 9.0 Moisture: wet Additives to soil: soda ash, water, activated carbon	Tilling (in situ, 3 times per week)	Treated soil

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TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Removal Action General Refining Company, GA 8/86 to 10/86 and 1/87 to 2/87 Shane Hitchcock (404) 347-3136	Solvent extraction/ Resource Conservation Technology Company Bellevue, WA	Sludge (3,448 tons)	Input: PCB - 5.0 ppm Lead - 10,000 ppm Output: PCB - insignificant Lead - concentrated in solids	Continuous operation Time: 2 hours pH: 10 Temp: 20 ?C Rate: 27 tons/day Moisture content: 60% Additives: Sodium hydroxide Triethylamine	Excavation Screening Neutralization Size Reduction Mixing	Oil - used a kiln Water - trea discharged Solids - soli and dispose site

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TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Removal Action Basket Creek Surface Impoundment, GA 11/92 to 2/93 Don Rigger (404) 347-3931	Vacuum extraction of soil pile with horizontal wells (ex situ)/OHM	Soil (2,000 yd^3)	VOCs TCE, PCE, MEK, MIBK, BTEX High 33% VOCs Average 1 to 5% Criteria: TCE - 0.5 mg/L TCLP PCE - 0.7 mg/L TCLP All VOCs met TCLP limits	Vacuum pressure monitored. 1,300 CFM/manifold. 3 manifolds 6 to 7 wells/manifold	Surface impoundment used for disposal of waste solvents. Built an enclosure over the site. Excavated the soil and screened it with a power screen. Stacked on PVC extraction wells. Recovered VOCs with duct work and fan. Vapors incinerated.	Residual so rejects from screening n limits and w disposed of nonhazardo RCRA Subt landfill. Inc 70,000 lb of
EPA Removal Action Zhiegner Refining Company 2/93 to 6/93 Dilshad Perera (908) 321-4356	Chemical treatment/ENSCO	Solid (100 lb)	Mercury initial concentration >10% mercury Final concentration of mercury in recyclable precipitate was >80%. Less than 260 ppm if mercury in tank nonrecycled salt.	Added salt to precipitate the mercury	Mercury pretreatment precipitated mercury salts into mercury sulfide so that the mercury can be recovered and recycled	Residual sa containing l 260 ppm me were incine site.

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TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Removal Action Vineland Chemical Company, NJ 12/92 Don Graham (908) 321-4345	Chemical treatment/ENSCO	Solid (100 lb)	Mercury initial concentration >10% mercury Final concentration of mercury in recyclable precipitate was >80%. Less than 260 ppm of mercury in nonrecycled salt.	Added salt to precipitate the mercury	Mercury pretreatment precipitated mercury salts into mercury sulfide so that the mercury can be recovered and recycled	Residual sa containing l 260 ppm me were incine site
EPA Removal Action Signo Trading International, Inc.,NY 10/20/87 to 10/21/87 Charles Fitzsimmons (201) 321-6608	KPEG dechlorination/ Galson Remediation, Syracuse, NY	Sludge (15 gallons)	Dioxin Input: 135 ppm Output: 1 ppb	Temperature: 150?C Time: Overnight	Excavation	Incineration residuals (w dioxin conta nation) at tr storage, an disposal fac
EPA Removal Action Avtex Fibers, VA 4/90 to 8/91 Vincent Zenone (215) 597-3038	Chemical treatment (oxidation using NaClO)/OH Materials, Findlay, OH (ERCS contractor)	Sludge/water from storage unit (2 million gallons)	Carbon disulfide Criteria: ?10 ppm - carbon disulfide in the effluent Input: 50 to 200,000 ppm carbon disulfide Output: ?10 ppm - carbon disulfide	Batch operation average retention time - 1 hour pH - 10 Additives: sodium hypochloride The retention time and reagent feed rates increased with increasing concentration of sludge in the contaminated water.	Pumping	Salts from t reaction we removed wi flocculation clarification existing trea plant, pH ac

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TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Army Saginaw Bay Confined Disposal Facility, MI 10/91 to 6/4/92 Jim Galloway (313) 226-6760	Soil washing; water with flocculent and surfactant as an additive/Bermann USA, Stafford Springs, CT	Sediment (150 yd^3)	PCBS	30 yd^3 of sediment treated per day	Dredging Screening Size reduction	Residuals w at the facilit Wastewater discharged confined dis facility
EPA & Navy Demo EPA Lab, NJ Deh Bin Chan (805) 982-4191	Chemical detoxification of chlorinated aromatic compounds	Soil	Dioxin, herbicides, chlorinated aromatic compounds. 99.9% decontamination achieved	Soil heated to 100-150 ?C if dehydrated	Excavation, Water content assessed.	Products ar toxic nor biodegradal
EPA Demo Douglassville, PA 10/87 Paul R. DePercin (513) 569-7797	Chemical treatment & immobilization	Soil, sediments, & sludge	Organic compounds, heavy metals, oil, & grease	In/ex situ. Sediments - underwater. Batch process at 120 tons/hour.	Blending	Hardened c like mass
DOE Demo INEL, ID 1992 Robert Montgomery (208) 525-3937	Physical separation/ chemical extraction	Sediments	Radionuclides & metals	Contaminants removed from leachate by ion exchange, reverse osmosis, precipitation, or evaporation	Screening, segregation, leaching with hot nitric acid	Solidificatio calcining le storage
EPA Demo Midwest, California, Australia 1987 S. Jackson Hubbard (513) 569-7507	SAREX chemical fixation process	Soil & sludge	Low level metals & organics	Catalyzed by lime and proprietary reagents	Blending with reagent, mixing, heating, curing	Vapors are and process before relea

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TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGI

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Demo Grand Calumet River Site, IL 1992 Mark Meckes (513) 569-7348	BEST? solvent extraction process	Oily sludges & soil	PCBs, PAHs, pesticides	pH >10	Hydrophobic and hydrophilic cycles by controlling temperature	Separation water, and solids
EPA Demo Santa Maria, CA 5/92 Annette Gatchett (513) 569-7697	Biogenesis_ soil washing process	Soil	Organics - oil, fuel, PCBs, PAHs 99% hydrocarbon removal with initial concentration up to 15,000 ppm	30-65 tons/hour	Agitated in unit with surfactant	Washwater oil/water se filter, and bi
DOE Demo Clemson Technical Center, SC Doug Mackensie (208) 526-6265	Enhanced Soil Washing with Soil*EX_	Soil & debris	Heavy metals, radionuclides, and organics	Particles smaller than 2 inches	Screening, dissolution, surfactant addition	Clean soil & recycle wat gas from or concentrate contaminan
EPA Demo 1992 Michelle Simon (513) 569-7469	RENEU? extraction technology	Soil	Organics up to 325,000 ppm	Operated under vacuum - 5-45 tons/hour	Sand, clay, and soil up to 3 in. diameter	Clean soil b
EPA & DOE Demo Montclair, West Orange & Glen Ridge Sites, NJ Mike Eagle (202) 233-9376	Soil washer for radioactive soil	Soils	Radionuclides- 56% volume reduction 40 pCu/g to 11 pCu/g	1 ton/hour	Attrition mills and hydro-classifiers	Filter press site disposa

TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Army Demo Sacramento Army Depot, CA 1992 Marlin Mezquita (415) 744-2393	Soil washing	Oxidation lagoon soils (12,000 yd^3)	Cd, Ni, Pb, Cu	Soil treated with wash reagent to extract contaminants	Wash liquid neutralized with caustic to precipitate metals	Precipitated landfilled
DOE Demo Fernald Site, OH Kimberly Nonfer (513) 648-6556	Soil washing	Soil	Uranium	Soil and leachant attrition scrubbed for 1 minute to solubilize uranium	Attrition scrubbing, gravity separation, screening	Wastewater treatment re
EPA Demo Coleman-Evans Site, FL Norma Lewis (513) 569-7665	Soil washing/ catalytic ozone oxidation	Soil, sludge, & groundwater	Organics - up to 20,000 ppm	Soil washing enhanced by ultrasound	Soil particles greater than 1 inch are crushed	Oxidation o wastewater for off-gas
EPA Demo Alaska Battery Enterprises Superfund Site, AK 1992 Hugh Masters (908) 321-6678	Soil washing plant	Soil	Heavy metals, radionuclides	Rate dependent on percentage of soil fines - up to 20 tons/hour	Deagglomeration, density separation, and material sizing	Concentrate contaminan containerize recirculated soil
EPA Demo MacGillis & Gibbs Superfund Site, MN 1989 Mary Stinson (908) 321-6683	Soil washing system	Soil	Removal: 89% PCP 88% PAHs	500 lb/hour 24 hour/day	Debris prescreening, soil mixed with water, separation (operations similar to mineral processing operations)	Wastewater in fixed film bioreactor

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TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Demo New Bedford Harbor, MA & O'Connor Site, ME 3/91 to 3/92 Laurel Staley (513) 569-7863	Solvent extraction	Soil, sludge, and wastewater	PCB 300-2,500 ppm 90-98% removal	Tray tower for water; extractor/decantors for solids and semi-solids	Phase-separation with solvent, solvent recovery	Heavy meta then Class I
EPA Demo Pensacola, FL 11/92 Teri Richardson (513) 569-7949	Volume reduction unit	Soils	Organics - creosote PCP, pesticides, PAHs, VOCs, SVOCs, metals	Up to 100 lb/hour	Particle separation and solubilization	Concentrate contaminan
EPA Demo Iron Mountain Mine Site, CA 1990 to 1991 S. Jackson Hubbard (513) 569-7507	Precipitation, microfiltration & sludge dewatering	Sludge & leachable soil	Heavy metals, non-volatile organics & solvents, oil, grease, pesticides, bacteria, solids	Up to 5% solids, 30 lb/hour of solids, 10 gpm of wastewater	Heavy metal precipitation, filtration, concentrated stream dewatering	Filter cakes 40-60% soli recycled
EPA *SITE* Demo Portable Equip. Salvage Co. Clackamas, OR 9/89 Edwin Barth (513) 569-7669	Chemfix process - solidification/stabili zation	Soil & Sludge	Solid waste	Uses soluble silicates and silicate-settling agents	Blend waste with dry alumina, calcium, and silica-based reagents	Produces fr solids. Cu a TCLP extra reduced 94-

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TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Navy Demo Naval Const. Battalion Ctr. Port Hueneme, CA 2/91 to 2/92 Jeff Heath (805) 982-1657	Solidification of Spent blasting	Blasting wastes containing abrasives, grit, sands	Lead, copper, and heavy metals	About 2 months required for design	Mixing of asphalt and other aggregates	<1% inert d (wood and r scrap) is pr
EPA *SITE* Demo Robins AFB Macon, GA 8/91 Terry Lyons (513) 569-7589	Solidification/stabili zation	Soil, sludge, liquid	Organics and inorganics	Uses proprietary bonding agents	Large debris must be prescreened	Non-leachir strength mo
EPA *SITE* Demo Selma Pressure Treating Selma, CA 11/90 Edward Bates (513) 569-7774	Solidification/stabili zation with silicate compounds	Groundwater, soil, sludge	Organics and inorganics	Silicate compounds	Pretreatment separation of coarse and fine materials	PCP leacha concentratio reduced up As, Cr, and immobilized
Imperial Oil Co./Champion Chemical Co. Superfund Site Morganville, NJ 12/88 S. Jackson Hubbard (513) 569-7507	Soliditech solidification/ stabilization process	Soil, sludge	Inorganics and organics, metals, ore, grease	Add water, Urrichem (proprietary additives), and pozzolanic material (fly ash or kiln dust)	Screen waste and introduce into batch mixer	Heavy meta untreated w were immob VOCs not d in treated w

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TABLE 3-8
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Small Arms Range, Naval Air Station Mayport, FL 1990 Barbara Nelson (805) 982-1668	Stabilization of small arms range	Soil	Lead and other heavy metals	Soil is mixed with sodium silicate, portland cement, and water	Screen soil to remove bullets (to be recycled) and other debris (landfill)	TCLP reduc 720 to 0.9 p to 0.2 ppm 0.2 ppm Zn

Sources: *Innovative Treatment Technologies: Annual Status Report* (EPA, 1993).
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

✍ 3.6 EX SITU THERMAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

The main advantage of ex situ treatments is that they generally require shorter time periods, and there is more certainty about the uniformity of treatment because of the ability to screen, homogenize, and continuously mix the soils. Ex situ processes, however, require excavation of soils leading to increased costs and engineering for equipment, possible permitting, and materials handling worker safety issues.

Thermal treatments offer quick cleanup times but are typically the most costly treatment group. This difference, however, is less in ex situ applications than in in situ applications. Cost is driven by energy and equipment costs and is both capital and O&M-intensive.

Thermal processes use heat to increase the volatility (separation); burn, decompose, or detonate (destruction); or melt (immobilization) the contaminants. Separation technologies include thermal desorption and hot gas decontamination. Destruction technologies include incineration, open burn/open detonation, and pyrolysis. Vitrification immobilizes inorganics and destroys some organics.

Separation technologies will have an off-gas stream requiring treatment. Destruction techniques typically have a solid residue (ash) and possibly a liquid residue (from the air pollution control equipment) that will require treatment or disposal. If the treatment is conducted on-site, the ash may be suitable for use as clean fill, or may be placed in an on-site monofill. If the material is shipped off-site for treatment, it will typically be disposed of in a landfill that may require pretreatment prior to disposal. It should be noted that for separation and destruction techniques, the residual that requires treatment or disposal is a much smaller volume than the original. Vitrification processes usually produce a slag of decreased volume compared to untreated soil because they drive off moisture and eliminate air spaces. A possible exception can occur if large quantities of fluxing agent are required to reduce the melting point of the contaminated soil.

Available ex situ thermal treatment technologies include high temperature thermal desorption, hot gas decontamination, incineration, low temperature thermal desorption, open burning/open detonation, pyrolysis, and vitrification. These technologies are discussed in Section 4 (Treatment Technology Profiles 4.21 through 4.27). Completed ex situ thermal treatment projects for soil, sediment, and sludge are shown in Table 3-9.

TABLE 3-9
COMPLETED PROJECTS: EX SITU THERMAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Remedial Action McKin, ME 7/86 to 2/87 Sheila Eckman (617) 573-5784	Thermal desorption/ Canonie Env. Services Corp., Porter, IN	Soil (11,500 yd^3 to a depth of 10 ft)	VOCs Criteria: 0.1 ppm TCE Input: Up to 1,000 ppm TCE Output: 0.1 ppm	Continuous operation 6 to 8 minutes' retention time 300 ?F	Excavation	Soils - solid disposed of on-site Vapors - air capture
EPA Remedial Action Otteti & Goss, NH 6/89 to 9/89 Stephen Calder (617) 573-9626	Thermal desorption/ Canonie Engineering	Soil (6,000 yd^3)	TCE, PCE, DCA, benzene Criteria: 1 ppm - Total VOCs and <100 ppm - Each individual VOC Output: <1 ppm - Total VOCs	Batch process	Excavation Screening	Carbon fron pollution co regenerated
EPA Remedial Action Outboard Marina/Waukegan Harbor (OU 3), IL 1/92 to 7/92 Cindy Nolan (312) 886-0400	Thermal desorption/ Canonie Environmental Services Porter, IN	Soil/sediments (16,000 $yd^{3)}$)	PCBs Initial 20,000-100,000 ppm 99% removal	Continuous with a retention time of 15 minutes and throughput of 8 to 10 tons/hour Temperature 1,100?F Moisture content 20% or less soda ash added to waste to meet DRE of 99.9999%	Excavation Mixing Dewatering	Cleaned so sediment st on-site cont cells. Wast discharged POTW.
EPA Remedial Action Cannon Engineering/MA 5/90 to 10/90 Richard Goehlert (617) 573-5742	Thermal soil aeration/Canonie Environmental Services Corp., Porter, IN	Soil (11,300 tons)	Criteria: 0.1 ppm - TCE, DCE, PCE 0.2 - Toluene, Xylene 0.5 - Vinyl chloride SVOCs - 3 ppm	Continuous operation 40 tons/hour 450 to 500 ?F Moisture content before treatment- 5 to 25% moisture	Excavation Screening Mixing Dewatering	Residuals fr pollution co disposed of Wastewater on-site

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TABLE 3-9

COMPLETED PROJECTS: EX SITU THERMAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTINUE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
			(total) Input: 500 to 3,000 ppm (total VOCs) Output: <0.25 ppm (total VOCs)	Additives - dry soil (to reduce moisture content)		
EPA Removal Action Drexler-RAMCOR, WA 7/92 to 8/92 Chris Field (206) 553-1674	Low temperature thermal desorption treatment. Thermally treat 3,000 tons of soil on-site up to 700 ?F/Four Seasons	Soil 3,000 tons (approximately 3,000 yd^3)	Petroleum hydrocarbons, polynuclear aromatics, BTEX (benzene, toluene, ethylbenzene, xylene) 200-ppm TPH was target. Initial TPH was 70,000 ppm (high) to 15,000-20,000 ppm (average)	16 hours/day 12 to 15 tons/hour Operating temperature up to 700 ?F	Excavation Screening Removed material greater than 2 inches. Rockwashing station for particles greater than 2 inches. Steam-cleaned large rocks.	Treated soil backfilled in excavated a site. Soil th meet the ta retreated. Wastewater treated on-s through car filters.
EPA Demo Wide Beach Development Superfund Site, NY & Outboard Marine Corp., IL 1991 & 1992 Paul dePercin (513) 569-7797	Anaerobic thermal processor	Soil & refinery wastes	PCBs (99% reduction), chlorinated pesticides, & VOCs	Thermal zones: preheat, retort, combustion, & cooling	Mixing occurs in rotary kiln	Vaporized contaminan through cyc baghouse, s and carbon.
EPA Demo Babcock & Wilcox, OH Laurel Staley (513) 569-7863	Cyclone Furnace	Soil	Organics & metals	820 ?F	Swirling action mixes air & fuel	Final produ resembles v glass (simila ISV's produ
EPA Demo Niagara-Mohawk Power Co., NY	High-Temperature Thermal Processor	Solids & sludges	VOCs, SVOCs, & PCBs	850 ?F, 150 ?F for safe handling	Rotation of screws moves material	Controlled b indirect con system & ac

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TABLE 3-9

COMPLETED PROJECTS: EX SITU THERMAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTINUE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
6/91 Ronald Lewis (513) 569-7856						carbon bed
EPA Demo Pesticide Site, AZ 9/92 Paul dePercin (513) 569-7797 Chetan Trivedi (219) 926-7169	Low-Temperature Thermal Aeration (LTTA®)	Soils, sediments & sludges	Removal efficiencies: >99%-VOCs @ 5,400 mg/kg >92%-pesticides @ 1,500 mg/kg 67-96% SVOCs @ 6.5 mg/kg	800 ?F	Dry, pug mill, cyclonic separators, baghouse, venturi scrubber, GAC.	Treated exh and liquid w Does not ge dioxins or fu
Army Demo Letterkenny Army Depot, PA 8/85 to 9/85 Capt. Kevin Keehan (410) 671-2054 Mike Cosmos (610) 701-7423	Low-Temperature Thermal Stripping	Soil	VOCs (chlorinated solvents & fuels); 99.9% destruction	Up to 650 ?F	Churning - Holo-Flite screw thermal processor	Gaseous ef with concen contaminan
EPA & Army Demo Tinker AFB, OK & Anderson Development Co. Superfund Site, MI 1989 Paul dePercin (513) 569-7797 Capt. Kevin Keehan (410) 671-2054 Mike Cosmos (610) 701-7423	Low-Temperature Thermal Treatment (LT3®)	Soil	VOCs & SVOCs; diesel fuel, gasoline & PAHs	Area required: 5,000 ft^2. Soil heated to 400-500 ?F. Treatment capacity was 18,000-20,000 lb/hour.	Covered troughs that house inter-meshed screw conveyors.	Organic pha disposed of
DOE Demo Energy Technology	Molten salt oxidation process	Liquids & solids	Radionuclides organics, oils,	800-1,000 ?C Typical residence time is 2	Waste passed through a sparged	Off-gas filte before relea

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TABLE 3-9

COMPLETED PROJECTS: EX SITU THERMAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTINUE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Engineering Center, ORNL, LANL Lawnie H. Taylor (301) 903-8119			graphite, chemical warfare agents, & explosives	seconds	bed of turbulent molten salt.	
EPA & DOE Demo Component Development & Integration Facility, MT 1991 Laurel Staley (513) 569-7863 R.C. Eschenback (707) 462-6522	Plasma ARC vitrification	Soils & sludge	Organics & metals	2,800-3,000 ?F in plasma centrifugal furnace	Fed into sealed centrifuge & heated to 1,800 ?F. Organics are evaporated.	Organic lad stream and laden vitrifie
DOI Demo Albany Metallurgy Research Center, OR Paul C. Turner (503) 967-5863	Vitrification furnace	Solids	Residues from Incineration of municipal waste	Electric arc furnace with water-cooled roof & sidewalls	Dedicated feeder and off-gas treatment.	Glassy slag metallic pha
EPA Demo ReSolve, Inc., Superfund Site, MA 1992 Paul dePercin (513) 569-7797 Carl Palmer (803) 646-2413	X*TRAX? thermal desorption	Soil	VOCs, SVOCs, & PCBs Average PCB removal efficiency: 99%	Heated rotary dryer, 750-950 ?F	Separation technique	Negligible c emission. N detected in gases
EPA *SITE* Demo Ogden Rsc Facility, San Diego, CA 3/89 Douglas Grosse (513) 569-7844	Circulating bed combustor	Soil, sludge, liquids, solids, slurry	Halogenated and non halogenated organic compounds, PCBs, dioxins	Combustion through hot cyclone (1,450-1,600 ?F)	Mixing wastes Limestone added to neutralize acid gases	Below perm

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TABLE 3-9

COMPLETED PROJECTS: EX SITU THERMAL TREATMENT FOR SOIL, SEDIMENT, AND SLUDGE (CONTINUE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA *SITE* Demo Monaca, PA 1991 Donald Oberacker (513) 569-7510	HRD flame reactor	Wastes, soil, solids, fluid, dust, slag, sludge with high metal content	Metals (zinc, lead, arsenic, silver, gold) and organics	Combustion in O_2 enriched chamber at 2,000 ?$^{+}$C	Requires dry wastes	Nonleachab disposal in
EPA *SITE* Demos (1) Tampa, FL, 8/87 (2) Rose Township/ Demode Road Super fund Site, MI, 11/87 John F. Martin (513) 569-7696	Infrared thermal destruction	Soil, sediment, liquid organic wastes mixed with sand or soil	Organics	Infrared radiant heat of up to 1,850 ?F	May needto restrict chloride levels in the feed	PCBs consi meet TSCA guidance 2 ppm in as
EPA *SITE* Demo EPA Combustion Research Facility, Jefferson, AK 11/87 to 1/88 Laurel Staley (513) 569-7863	PYRETRON® thermal destruction	Soil, sludge, solid waste	Organics	O_2 enhanced combustion	40% contaminated soil, 60% decanter tank tar sludge from coking operations	DRE for all >99.99%

Sources: *Innovative Treatment Technologies: Annual Status Report* (EPA, 1993).
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

✍ 3.7 OTHER TREATMENT TECHNOLOGIES FOR SOIL, SEDIMENT, AND SLUDGE

Other treatment technologies for soil, sediment, and sludge include excavation and off-site disposal, containment technologies, and natural attenuation. These treatments are discussed in more detail in Section 4 (Treatment Technology Profiles 4.28 and 4.29). Completed projects for other treatment technologies for soil, sediment, and sludge are shown in Table 3-10.

TABLE 3-10
COMPLETED PROJECTS: OTHER TREATMENTS FOR SOIL, SEDIMENT, AND SLUDGE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Demo Edison, NJ 1991 Laurel Staley (513) 569-7863	Carver-Greenfield Process	Soils, sediments, & sludges	Oil soluble organics-100% TPH and 95% oil removal	5-10 lb of "carrier oil" added for 1 lb of soil	Extracted oil mixture separated in oil/water separator	Dry final sol product with than 1% ca
EPA Demo Carter Industrial, MI Shaver's Farm, GA Hopkinsville, KY Naomi Berkley (513) 569-7854	Debris washing system	Debris	Reduction- PCB to 10 µg/100 cm^2 Benzonitrile from 4,556 to 10 µg/100 cm^2 Dicamba from 25 to 1 µg/100 cm^2	Spray detergent and water @ 140?F, 60 lb/psig	300-gallon spray and waste tank	Wash soluti treated oil/w separator, fi carbon, and exchange
DOI, Army, EPA Demo Saginaw Bay Confined Disposal Facility, MI; Toronto, Canada 10/91 to 6/92 S. Jackson Hubbard (513) 569-7507	Particle Separation Process	Sediments (30 yd^3/day)	PCBs, heavy metals, radionuclides	Contaminant and grain size analysis	Screening, water and chemicals added, attrition scrubbing, particle separation	Output soil, clays, and w water
EPA Demo IN, MI, OH, SD, VA, WI 1992 S. Jackson Hubbard (513) 569-7507	MAECTITE?	Soils, sludges, other waste materials, & debris	Lead	Up to 100 tons/hour; curing for 4 hours	Blending with proprietary powder and reagent solution	Soil-like res reduced vol suitable for a special wa
EPA Demo Palmerton Zinc Superfund Site, PA 1990 John Martin (513) 569-7758	Membrane microfiltration	Liquid wastes	Solid particles in li quid wastes-removal averaged 99.95% for Zn & TSS	Filter press 45 psi	Tyvek (T-980) spun-bound olefin filter	Filter cake 40-60% soli

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TABLE 3-10

COMPLETED PROJECTS: OTHER TREATMENTS FOR SOIL, SEDIMENT, AND SLUDGE (CONTINUED)

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Demo Toronto Port Industrial District, Canada 1991 Teri Richardson (513) 569-7949	Soil recycling	Soils	Organics and Inorganics	Inorganics extracted; organics extracted and biodegraded.	Soil washing, metal dissolution, chemical hydrolysis with biodegradation	Metals reco pure form. fill
EPA Demo Hamilton Harbor, Canada 1992 Gordon Evans (513) 569-7684	Thermal gas phase reduction	Soil, sludge, liquids, & gases	Hydrocarbons	850 ?C on-line mass spectrometer	Reduction of hydrocarbons in presence of hydrogen	Offgas strea
DOE Integrated Demo (1,2) Chemical and Mixed Waste Landfills, Albuquerque, NM (3) Mixed Waste Landfill at Kirkland AFB, NM Jennifer Nelson (505) 845-8348	Mixed waste landfill	In situ landfills in arid environments which contain complex mixtures	Mixed wastes containing heavy metals in complex mixtures with organic, inorganic, and radioactive wastes	Integration of existing technologies, including thermally enhanced vapor extraction system, flexible membrane lining system, and directional drilling	Characterization and remediation technology demos	Goal is to re most rapidly consti-tuent isolate the r ing constitu 30 years (in permanently
DOE Integrated Demo, DOE Savannah River Site, Aiken, GA Terry Walton (803) 725-5218	Organics in soil and groundwater at nonarid sites	Soils, groundwater @ nonarid sites emphasizing in situ remediation	Volatile organics, such as TCE and PCE	Integrated demo includes many technologies- no specific parameters given	Directional well drilling precedes the in situ air stripping	Integrated c includes ma technologie specific par given
DOE Integrated Demo, 4 DOE sites; at (1) Hanford (2) Fernald, ID (3) Oak Ridge	Underground storage tanks emphasizing the single-shell storage tanks located at the	Groundwater, soil	Tank waste consti-tuents ranging from Na-nitrates to trans-uranics, in 3 forms: supernatant (liquid),	UST-ID is pursuing technologies in two general areas: characterization/retrieval technologies &	Integrated demo includes many technologies- no specific parameters given	Integrated c includes ma technologie specific par given

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TABLE 3-10

COMPLETED PROJECTS: OTHER TREATMENTS FOR SOIL, SEDIMENT, AND SLUDGE (CONTINUED)

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
(4) Savannah River 2/91 Roger Gilchrist (509) 376-5310	Hanford site.		sludges, and salt-cake (which can be as hard as cement)	separations/low-level waste technologies. No/few specific parameters available		
DOE Integrated Demo, Fernald Environmental Project Cincinnati, OH Kimberly Nonfer (513) 648-6914	Uranium soil	Soil	Uranium	Selective extraction of uranium. Char-acterize uranium in-volved (especially dominant hexavalent oxidation state)	Extraction without physio-chemical damage to soil	Concentrate uranium str
DOI Tech Demo Tests conducted in St. John's County, FL George A. Savanick U.S. Bureau of Mines 5629 Minnehaha Ave., South Minneapolis, NJ 55417	Borehole slurry extraction	Soils, especially sand, stone, or clays	Uranium, oil	Soil is reduced in situ to a pumpable slurry. Single 6 to 12-inch-diameter borehole	Soil is reduced in situ to a pumpable slurry	After treatm waste mate pumped ba cavity to pr surface sub
DOI Tech Demo (EPA & Bureau of Mines) Bureau of Mines Salt Lake City Research Center 4/90 J.P. Allen (801) 584-4147	Characterization and treatment of contaminated Great Lakes sediment	Sediment	Organics and inorganics	Physical separation (mineral processing) technologies, including magnetic separation, gravity separation, and froth flotation, being investigated	Volume reduction followed by more expensive treatment	Physical se is considere pretreatmer some small amount of concentrate material will further decontamin

Sources: *Innovative Treatment Technobgies: Annual Status Report* (EPA, 1993).
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

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✍ 3.8 IN SITU BIOLOGICAL TREATMENT FOR GROUNDWATER, SURFACE WATER, AND LEACHATE

The main advantage of in situ treatment is that it allows groundwater to be treated without being brought to the surface, resulting in significant cost savings. In situ treatment, however, generally requires longer time periods, and there is less certainty about the uniformity of treatment because of the variability in aquifer characteristics and because the efficacy of the process is more difficult to verify.

Bioremediation techniques are destruction techniques directed toward stimulatin g the microorganisms to grow and use the contaminants as a food and energy source by creating a favorable environment for the microorganisms. Generally, this means providing some combination of oxygen, nutrients, and moisture, and controlling the temperature and pH. Sometimes, microorganisms adapted for degradation of the specific contaminants are applied to enhance the process.

Biological processes are typically easily implemented at low cost. Contaminants are destroyed and little to no residual treatment is required. Some compounds, however, may be broken down into more toxic by-products during the bioremediation process (e.g., TCE to vinyl chloride). In in situ applications, these by-products may be mobilized in groundwater if no control techniques are used. Typically, to address this issue, bioremediation will be performed above a low permeability soil layer and with groundwater monitoring wells downgradient of the remediation area. This type of treatment scheme requires aquifer and contaminant characterization and may still require extracted groundwater treatment.

Although not all organic compounds are amenable to biodegradation, bioremediation techniques have been successfully used to remediate groundwater contaminated by petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Bioremediation has no expected effect on inorganic contaminants.

The rate at which microorganisms degrade contaminants is influenced by the specific contaminants present; temperature; oxygen supply; nutrient supply; pH; the availability of the contaminant to the microorganism (clay soils can adsorb contaminants making them unavailable to the microorganisms); the concentration of the contaminants (high concentrations may be toxic to the microorganism); the presence of substances toxic to the microorganism, e.g., mercury; or inhibitors to the metabolism of the contaminant. These parameters are discussed in the following paragraphs.

To ensure that **oxygen** is supplied at a rate sufficient to maintain aerobic conditions, forced air, liquid oxygen, or hydrogen peroxide injection can be used. The use of hydrogen peroxide is limited because at high concentrations (above 100 ppm, 1,000 ppm with proper acclimation), it is toxic to microorganisms. Also, hydrogen peroxide tends to decompose into water and oxygen rapidly in the presence of some constituents, thus reducing its effectiveness.

Anaerobic conditions may be used to degrade highly chlorinated contaminants. This can be followed by aerobic treatment to complete biodegradation of the

partially dechlorinated compounds as well as the other contaminants.

Nutrients required for cell growth are nitrogen, phosphorous, potassium, sulfur, magnesium, calcium, manganese, iron, zinc, and copper. If nutrients are not available in sufficient amounts, microbial activity will stop. Nitrogen and phosphorous are the nutrients most likely to be deficient in the contaminated environment and thus are usually added to the bioremediation system in a useable form (e.g., as ammonium for nitrogen and as phosphate for phosphorous). Phosphates are suspected to cause soil plugging as a result of their reaction with minerals, such as iron and calcium, to form stable precipitates that fill the pores in the soil and aquifer.

pH affects the solubility, and consequently the availability, of many constituents of soil, which can affect biological activity. Many metals that are potentially toxic to microorganisms are insoluble at elevated pH; therefore, elevating the pH of the treatment system can reduce the risk of poisoning the microorganisms.

Temperature affects microbial activity in the environment. The biodegradation rate will slow with decreasing temperature; thus, in northern climates bioremediation may be ineffective during part of the year unless it is carried out in a climate-controlled facility. The microorganisms remain viable at temperatures below freezing and will resume activity when the temperature rises.

Provisions for heating the bioremediation site, such as use of warm air injection, may speed up the remediation process. Too high a temperature, however, can be detrimental to some microorganisms, essentially sterilizing the aquifer.

Temperature also affects nonbiological losses of contaminants mainly through the evaporation of contaminants at high temperatures. The solubility of contaminants typically increases with increasing temperature; however, some hydrocarbons are more soluble at low temperatures than at high temperatures. Additionally, oxygen solubility decreases with increasing temperature.

Bioaugmentation involves the use of cultures that have been specially bred for degradation of a variety of contaminants and sometimes for survival under unusually severe environmental conditions. Sometimes microorganisms from the remediation site are collected, separately cultured, and returned to the site as a means of rapidly increasing the microorganism population at the site. Usually an attempt is made to isolate and accelerate the growth of the population of natural microorganisms that preferentially feed on the contaminants at the site. In some situations different microorganisms may be added at different stages of the remediation process because the contaminants change in abundance as the degradation proceeds. USAF research, however, has found no evidence that the use of non-native microorganisms is beneficial in the situations tested.

Cometabolism, in which microorganisms growing on one compound produce an enzyme that chemically transforms another compound on which they cannot grow, has been observed to be useful. In particular, microorganisms that degrade methane (methanotrophic bacteria) have been found to produce enzymes that can initiate the

oxidation of a variety of carbon compounds.

Treatability or feasibility studies may be performed to determine whether bioremediation would be effective in a given situation. The extent of the study can vary depending on the nature of the contaminants and the characteristics of the site. For sites contaminated with common petroleum hydrocarbons (e.g., gasoline and/or other readily degradable compounds), it is usually sufficient to examine representative samples for the presence and level of an indigenous population of microbes, nutrient levels, presence of microbial toxicants, and aquifer characteristics.

Available in situ biological treatment technologies include co-metabolic processes, nitrate enhancement, and oxygen enhancement with either air sparging or hydrogen peroxide (H_2O_2). These technologies are discussed in Section 4 (Treatment Technology Profiles 4.30 through 4.33). Completed in situ biological treatment projects for groundwater, surface water, and leachate are shown in Table 3-11.

Implementation of biological treatment in vadose zone soils differs from that of soils below the water table largely in the mechanism of adding required supplemental materials, such as oxygen and nutrients. For saturated soils, nutrients may be added with and carried by reinjected groundwater. Oxygen can be provided by sparging or by adding chemical oxygen sources such as hydrogen peroxide. Surface irrigation may be used for vadose zone soils. Bioventing oxygenates vadose zone soils by drawing air through soils using a network of vertical wells.

TABLE 3-11
COMPLETED PROJECTS: IN SITU BIOLOGICAL TREATMENT FOR GROUNDWATER, SURFACE WATER, AND

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Naval Communication Station, Scotland 2/85 to 10/85 (U.S. Navy) Deh Bin Chan (805) 982-4191	Bioremediation In situ soil, in situ groundwater	Soil, groundwater Soil quantity approximately 800 m^2 in area, depth unknown	TPH (No. 2 diesel fuel)	Microorganisms function best between 20 ?C and 35 ?C.	Runoff water collected in a trench	None
DOE Demo Savannah River Site, SC Nate Ellis (803) 952-4846 Brian Loony (803) 952-5181	Aerobic Biodegradation	Groundwater	TCE, PCE @ 1,000 ppb; 90% removal efficiency	Aquifers must be homogenous	Methanotrophic fluidized bed or trickle filter bioreactor	<1 lb/day pr
EPA Demo Williams AFB, AZ Completed in 1992 Kim Lisa Kreiton (513) 569-7328 David Mann (219) 868-5823	Augmented subsurface bioremediation	Soil & water	Hydrocarbons (halogenated and nonhalogenated)	In situ	Insertion of microaerophilic bacteria and nutrients. Hardy bacteria can treat contaminants over a wide temperature range.	Only degrad products ar H_2O
DOE Savannah River Site, SC Terry C. Hazen (803) 725-5178	Biodegradation	Soil & groundwater	TCE, PCE declined to <2 ppb	In situ	Injection of 1-4% methane/air into aquifer	None
DOE Demo Hanford Site, WA Thomas M. Brouns (509) 376-7855 Rodney S. Skeen (509) 376-6371	Biological treatment	Groundwater	Nitrate reduced by 99% from 400 ppm. CCl_4 reduced by 93% from 200 ppb	In situ	Provides ultimate destruction of contaminant	No spent ac carbon nee disposed
Air Force & DOE Demo Tinker AFB, OK	In situ & above-ground biological treatment of	Groundwater	80% destruction of TCE	In situ or in a bioreactor	Bioreactor design uses methane degrading bacteria	TCE destro

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TABLE 3-11
COMPLETED PROJECTS: IN SITU BIOLOGICAL TREATMENT FOR GROUNDWATER, SURFACE W

(CONTINUED)

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
1989 Alison Thomas (904) 283-6028	trichloroethylene				to co-metabolize TCE	
Air Force Demo Eglin, AFB, FL 1/94-10/94 Alison Thomas (904) 283-6028	In situ anaerobic biodegradation	Groundwater	Jet fuel (toluene, ethylbenzene, xylene)	In situ; nitrate is added to serve as electron acceptor		Benzene is recalcitrant strict anaer conditions
Air Force Demo Kelly AFB, TX & Eglin AFB, FL Catherine M. Vogel (904) 283-6036	In situ biodegradation	Soil & groundwater	Hydrocarbons- fuels, fuel oils, & nonhalogenated solvents	In situ	Nutrients introduced into aquifer through irrigation wells- some precipitation problems occurred	
DOI Demo Picatinny Arsenal, NJ Thomas E. Imbrigiotta (609) 771-3900	In situ biodegradation	Groundwater	82% removal of vapor-phase TCE after 8 days	In situ - Vapor stream is amended with oxygen and methane, propane, or natural gas	Venting unsaturated soil or sparging contaminated well near source	TCE is ana broken dow DCE then V finally to eth which will b and volatiliz
DOI Demo Defense Fuel Supply Point, SC Late summer 1993 Dr. Don A. Vroblesky (803) 750-6115	In situ enhanced bioremediation	Groundwater	Jet fuel	In situ	Uncontaminated groundwater is amended with nutrients and pumped into a series of infiltration galleries	Groundwate extracted a discharged treatment fa
DOE Tech Demo (USGS) Galloway Township, NJ	In situ vapor extraction and bioventing desig	Soil & groundwater	Gasoline	AIRFLOW - an adaption of the USGS groundwater flow	MODFLOW to perform airflow simulations	

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TABLE 3-11
COMPLETED PROJECTS: IN SITU BIOLOGICAL TREATMENT FOR GROUNDWATER, SURFACE W

(CONTINUED)

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
1988 Herbert T. Buxton (609) 771-3900	bioventing design			simulator	simulations	

Sources: *Innovative Treatment Technologies: Annual Status Report* (EPA, 1993).
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

✍ 3.9 IN SITU PHYSICAL/CHEMICAL TREATMENT FOR GROUNDWATER, SURFACE WATER, AND LEACHATE

The main advantage of in situ treatments is that they allow groundwater to be treated without being brought to the surface, resulting in significant cost savings. In situ processes, however, generally require longer time periods, and there is less certainty about the uniformity of treatment because of the variability in aquifer characteristics and because the efficacy of the process is more difficult to verify.

Physical/chemical treatment uses the physical properties of the contaminants or the contaminated medium to destroy (i.e, chemically convert), separate, or contain the contamination. Passive treatment walls separate and destroy the contaminant from in situ groundwater. Air sparging, directional wells, dual phase extraction, free product recovery, hot water or steam flushing/stripping, and vacuum vapor extraction are separation techniques. Slurry walls can be used to contain contaminated areas so that aquifer groundwater will flow around them without becoming contaminated. Hydrofracturing is an enhancement technique.

Available in situ physical/chemical treatment technologies include air sparging, directional wells, dual phase extraction, free product recovery, hot water or steam flushing/stripping, hydrofracturing, passive treatment walls, slurry walls, and vacuum vapor extraction. These treatment technologies are discussed in Section 4 (Treatment Technology Profiles 4.34 through 4.42). Completed in situ physical/chemical treatment projects for groundwater, surface water, and leachate are shown in Table 3-12.

Physical/chemical treatment is typically cost effective and can be completed in short time periods (in comparison with biological treatment). Equipment is readily available and is not engineering or energy-intensive. Treatment residuals from separation techniques will require treatment or disposal, which will add to the total project costs and may require permits.

TABLE 3-12
COMPLETED PROJECTS: IN SITU PHYSICAL/CHEMICAL TREATMENT FOR GROUNDWATER, SURFACE WAT

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Navy Demo Seal Beach Navy Weapons Station, CA 1991 Vern Novstrup (805) 982-2636 Rebecca Coleman-Roush (805) 644-5892	Groundwater vapor recovery system	Groundwater	VOCs	In situ - air permitting	Injection & extraction wells are placed inside and outside of contamination area	Waste hydr to internal combustion
DOE Demo Savannah River Site, SC 7/90-12/90 Mike O'Rear (803) 725-5541	In situ air stripping with horizontal wells	Soil & groundwater	TCE & PCE Initial concentrations: 5,000 ppm; stabilized to 200-300 ppm	In situ (horizontal wells) Extraction average 110 lb of VOCs/day	Air injection below aquifer - air extraction above.	Off-gas stre
DOE Demo Hanford Reservation, WA Steve Stein (206) 528-3340	Air Sparging	Groundwater	VOCs	In situ - In well air stripping	Surfactants or catalysts added if needed	Requires ai treatment
EPA Demo National Lead Industry, NJ 10/93 Carolyn Esposito (908) 906-6895	FORAGER® sponge	Waters	Heavy metals 90% removal Sponge can scavenge metals at ppm or ppb in industrial discharges	1 bed volume/minute control pH, temp, total ionic content	Open-celled cellulose sponge	Regeneratio incineration metals-satu sponge

Sources: *Innovative Treatment Technologies: Annual Status Report* (EPA, 1993).
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

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✍ 3.10 EX SITU BIOLOGICAL TREATMENT FOR GROUNDWATER, SURFACE WATER, AND LEACHATE

The main advantage of ex situ treatment is that it generally requires shorter time periods, and there is more certainty about the uniformity of treatment because of the ability to monitor and continuously mix the groundwater. However, ex situ treatment requires pumping of groundwater, leading to increased costs and engineering for equipment, possible permitting, and material handling.

Bioremediation techniques are destruction techniques directed toward stimulating the microorganisms to grow and use the contaminants as a food and energy source by creating a favorable environment for the microorganisms. Generally, this means providing some combination of oxygen, nutrients, and moisture, and controlling the temperature and pH. Sometimes, microorganisms adapted for degradation of the specific contaminants are applied to enhance the process.

Biological processes are typically easily implemented at low cost. Contaminants are destroyed and little to no residual treatment is required; however, some compounds may be broken down into more toxic by-products during the bioremediation process (e.g., TCE to vinyl chloride). An advantage over the in situ applications is that in ex situ applications, these by-products are contained in the treatment unit until nonhazardous end-products are produced.

Although not all organic compounds are amenable to bioremediation, techniques have been successfully used to remediate soils, sludges, and groundwater contaminated by petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Bioremediation is not applicable for treatment of inorganic contaminants.

The rate at which microorganisms degrade contaminants is influenced by the specific contaminants present; temperature; oxygen supply; nutrient supply; pH; the availability of the contaminant to the microorganism (clay soils can adsorb contaminants making them unavailable to the microorganisms); the concentration of the contaminants (high concentrations may be toxic to the microorganism); the presence of substances toxic to the microorganism, e.g., mercury; or inhibitors to the metabolism of the contaminant. These parameters are discussed briefly in the following paragraphs.

Oxygen level in ex situ applications is easier to control than in in situ applications and is typically maintained by mechanical mixing or air sparging.

Anaerobic conditions may be used to degrade highly chlorinated contaminants. This can be followed by aerobic treatment to complete biodegradation of the partially dechlorinated compounds as well as the other contaminants.

Nutrients required for cell growth are nitrogen, phosphorous, potassium, sulfur, magnesium, calcium, manganese, iron, zinc, and copper. If nutrients are not available in sufficient amounts, microbial activity will stop. Nitrogen and phosphorous are the nutrients most likely to be deficient in the contaminated

environment and thus are usually added to the bioremediation system in a useable form (e.g., as ammonium for nitrogen and as phosphate for phosphorous).

pH affects the solubility, and consequently the availability, of many constituents of soil, which can affect biological activity. Many metals that are potentially toxic to microorganisms are insoluble at elevated pH; therefore, elevating the pH of the treatment system can reduce the risk of poisoning the microorganisms.

Temperature affects microbial activity in the treatment unit. The biodegradation rate will slow with decreasing temperature; thus, in northern climates bioremediation may be ineffective during part of the year unless it is carried out in a climate-controlled facility. The microorganisms remain viable at temperatures below freezing and will resume activity when the temperature rises. Too high a temperature can be detrimental to some microorganisms, essentially sterilizing the soil.

Temperature also affects nonbiological losses of contaminants mainly through the volatilization of contaminants at high temperatures. The solubility of contaminants typically increases with increasing temperature; however, some hydrocarbons are more soluble at low temperatures than at high temperatures. Additionally, oxygen solubility decreases with increasing temperature. Temperature is more easily controlled ex situ than in situ.

Bioaugmentation involves the use of cultures that have been specially bred for degradation of a variety of contaminants and sometimes for survival under unusually severe environmental conditions. Sometimes microorganisms from the remediation site are collected, separately cultured, and returned to the site as a means of rapidly increasing the microorganism population at the site. Usually an attempt is made to isolate and accelerate the growth of the population of natural microorganisms that preferentially feed on the contaminants at the site. In some situations different microorganisms may be added at different stages of the remediation process because the contaminants in abundance change as the degradation proceeds. USAF research, however, has found no evidence that the use of non-native microorganisms is beneficial in the situations tested.

Cometabolism, in which microorganisms growing on one compound produce an enzyme that chemically transforms another compound on which they cannot grow, has been observed to be useful. In particular, microorganisms that degrademethane (methanotrophic bacteria) have been found to produce enzymes that can initiate the oxidation of a variety of carbon compounds.

Treatability or feasibility studies are used to determine whether bioremediation would be effective in a given situation. The extent of the study can vary depending on the nature of the contaminants and the characteristics of the site. For sites contaminated with common petroleum hydrocarbons (e.g., gasoline and/or other readily degradable compounds), it is usually sufficient to examine representative samples for the presence and level of an indigenous population of microbes, nutrient levels, presence of microbial toxicants, and soil characteristics such as pH, porosity, and moisture.

An available ex situ biological treatment technology is the use of bioreactors. This technology is discussed in Section 4 (Treatment Technology Profile 4.43). Completed ex situ biological treatment projects for groundwater, surface water, and leachate are shown in Table 3-13.

TABLE 3-13
COMPLETED PROJECTS: EX SITU BIOLOGICAL TREATMENT FOR GROUNDWATER, SURFACE WATER, AND

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
DOI Demo Bureau of Mines Tom Jeffers (801) 524-6164	BIO-FIX beads	Water	Metals - lead, cadmium, arsenic	Porous polymeric biomass beads with affinity for metals	Excellent handling - low maintenance	Adsorbed m removed us mineral acid
EPA Demo MacGillis & Gibbs Superfund Site, MN 7/89 to 9/89 Mary Stinson (908) 321-6683 Dennis Chilcote (612) 942-8032	Biological aqueous treatment system	Groundwater	PCP reduced to <1 ppm. Lowest flow removed 99% of contaminants	In mix tank, pH is adjusted & inorganic nutrients added	Mixing	Discharged POTW or re site
DOI Demo Late Summer 1993 Paulette Altringer Darren Belin (801) 584-4152 or 4155	Biologicalarsenic remediation	Wastewaters	Arsenic reduced from 13 to <0.5 mg/L	Addition of anaerobic sulfate-reducing bacteria	Two stage reactor, arsenic precipitation and column system	Minimum vo arsenic prec sludge
DOI Demo Bureau of Mines, NV 6/92 to 10/92 Paulette Altringer Richard H. Lien (801) 584-4152 or 4106	Biological cyanide detoxification	Wastewaters	Cyanide reduced from 20 ppm to 2 ppm	Flow rate up to 300 gpm Greater than 40-ppm phosphate	Bio-activated water use to rinsed metal waste heap	Chemical tr as a polishi
DOI Demo Bureau of Mines, UT Summer 1993 Paulette Altringer D. Jack Adams (801) 584-4152 or 4148	Biological reduction of selenium	Process & wastewaters	Selenium reduced from 30 to 1.2 ppm in 144 hours; 4.2 to 1.6 ppm in 48 hours. Selenium in uranium wastewater reduced from 0.58 to 0.03 ppm in 48 hours.	Uses on-site equipment (carbon tanks, sand filters) to reduce cost. Activated carbon or sand serves as growth surface for bacteria.	Wastewater and nutrient pumped through bed. Commercial fertilizers and/or sugar containing agricultural wastes provide bacterial nutrient	Selenium is precipitated removed by or cross-flow filtration

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TABLE 3-13
COMPLETED PROJECTS: EX SITU BIOLOGICAL TREATMENT FOR GROUNDWATER, SURFACE W

(CONTINUED)

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
					supplements	
Navy Demo, Naval Weapons Station Seal Beach, CA Steve MacDonald (310) 594-7273 Carmen Lebron (805) 982-1615	Bioremediation of aromatic hydrocarbons	Soil & groundwater	1 ppb to 4 ppm of BTEX	Three 80-liter bioreactors at combined capacity of 72 liters/day	Native microorganisms. Site soil is placed in bioreactors and contaminated groundwater is pumped through bioreactors	Effluent clea drinking wa standards f
EPA Demo St. Joseph, MI Ronald Lewis (513) 569-7856 Steve Lupton (708) 391-3224	Immobilized cell bioreactor (ICB) biotreatment system	Groundwater and industrial wastewater	>99% removal efficiencies of organics	Pretreatment- pH adjustment and oil/water separation. Proprietary reactor medium and design maximized biological degradation	Aerobic/Anaerobic fixed film bioreactor	Contaminar CO_2, water, biomass. T effluent pro reinjected
Air Force & DOE Demo Tinker AFB, OK 1989 Alison Thomas (904) 283-6028	In situ & aboveground biological treatment of trichloroethylene	Groundwater	80% destruction of TCE	In situ or in a bioreactor	Uses methane-degrading bacteria to co-metabolize TCE	TCE degrad

Sources: *Innovative Treatment Technologies: Annual Status Report* (EPA, 1993).
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

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✍ 3.11 EX SITU PHYSICAL/CHEMICAL TREATMENT FOR GROUNDWATER, SURFACE WATER, AND LEACHATE

The main advantage of ex situ treatment is that it generally requires shorter time periods, and there is more certainty about the uniformity of treatment because of the ability to monitor and continuously mix the groundwater. Ex situ treatment, however, requires pumping of groundwater, leading to increased costs and engineering for equipment, possible permitting, and material handling.

Physical/chemical treatment uses the physical properties of the contaminants or the contaminated medium to destroy (i.e, chemically convert), separate, or contain the contamination. UV oxidation is a destruction technology, and all other technologies included in this subsection are separation technologies.

Physical/chemical treatment is typically cost effective and can be completed in short time periods (in comparison with biological treatment). Equipment is readily available and is not engineering or energy-intensive. Treatment residuals from separation techniques will require treatment or disposal, which will add to the total project costs and may require permits.

Available ex situ physical/chemical treatment technologies include air sparging, filtration, ion exchange, liquid phase carbon adsorption, precipitation, and UV oxidation. These technologies are discussed in Section 4 (Technology Profiles 4.44 through 4.49). Completed ex situ physical/chemical treatment projects for groundwater, surface water, and leachate are shown in Table 3-14.

TABLE 3-14
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR GROUNDWATER, SURFACE WA

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Removal Action Crown Plating, MO 10/1/89 to 12/31/89 (Removal) Mark Roberts (913) 236-3881	Dechlorination using the KPEG process/EPA removal contractor	Liquid (5 gallons)	Criteria: Dioxin: <1 ppb Input: Silvex - 10,000 ppm Dioxin equivalents - 24.18 ppb Output: Silvex - 32 ppb Dioxin equivalents - 0.068 ppb	Batch operation Retention time - 36 hours (including time of equipment breakdown) Temperature - 72 ?C pH - 13 Moisture content - 100%	Groundwater extraction	Built an on-s vacuum for emissions c Contaminat residual oil incinerated
EPA Demo Lake Charles Treatment Center, LA Randy Parker (513) 569-7271	PO*WW*ER ? evaporation & catalytic oxidation	Groundwater & wastewaters	Volatile & non-volatile organic compounds, salts, metals, volatile inorganics	0.25 gpm pilot-plant	Evaporation & oxidation	Concentrate contaminan disposed of treated furth
DOE Demo Lawrence Livermore National Laboratory, CA 1991 Jesse L. Yow, Jr. (510) 422-3521	Solar Detoxification	Groundwater	VOCs	Exposed to sunlight & nontoxic catalyst (TiO_2)	Pumping, solar detox, pH adjustment, catalyst addition	Catalyst filte and water s secondary t
Army Demo USACE-WES, MS Mark Bricka (601) 634-3700	Xanthate treatment	Groundwater & wastewater	Heavy metals	Ion exchange with xanthated material	Precipitation, sedimentation, and filtration	Concentrate sludge
EPA Demo San Fernando Valley Groundwater Basin Superfund Site, CA	Integrated vapor extraction & steam vacuum stripping	Soil & groundwater	Initial concentration: up to 2.2 ppm TCE up to 11 ppm PCE Removal:	Groundwater: 1,200 gpm Soil gas: 300 ft/min	Groundwater: Steam stripping in tower Soil: SVE	Carbon sho regenerated hours

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TABLE 3-14
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR GROUNDWATER, SURFACE

(CONTINUED)

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
1990 Norma Lewis (513) 569-7665			up to 99.9% VOCs			
EPA Demo Coleman-Evans Site, FL Norma Lewis (513) 569-7665	Soil washing/catalytic ozone oxidation	Soil, sludge, & groundwater	Organics - 1-20,000 ppm	Soil washing enhanced by ultrasound followed by oxidation	Soil particles larger than 1 inch are crushed	Carbon filte gas
Navy Demo Bangor SUBASE, WA Spring 1993 Carmen LeBron (805) 982-1616	Advanced Oxidation Process	Groundwater	Ordnance - treated to 2.9 ppb TNT and 0.8 ppb RDX	Maintain pH	UV oxidation, H_2O_2, and O_3 to generate hydroxyl radicals	Possible tox byproducts
Navy Demo U.S. Navy Site, NJ 1991 Andy Law (805) 982-1650	Advanced Oxidation Process	Groundwater	Organics - TOC 50-100 ppm	Maintain pH	UV oxidation, H_2O_2, and O_3 to generate hydroxyl radicals	Contaminar destruction
Army Demo Fort Dix, NJ Steve Maloney (217) 373-6740	Catalytic Decontamination	Groundwater	Reduction: 0% TOC up to 90% VOC	Ex situ	Ozone injection and stripping	Air stream - in catalytic recycled
Air Force & EPA Demo Edwards AFB, CA 3/93 Richard Eilers (513) 569-7809	CAV-OX® Process	Groundwater & wastewater	Organics - 96-100% reduction	H_2O_2 and metal catalysts added if needed	Hydrodynamic cavitation and UV oxidation	Contaminar destruction
EPA & DOE Demo Rocky Flats Facility, CO	Filtration	Waters	"Polishing" filtration process for heavy metals and non-tritium	Specific control - water chemistry, water flux, and bed volume	Sorption, chemical complexing, and hydroxide	Concentrate sludge

TABLE 3-14
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR GROUNDWATER, SURFACE

(CONTINUED)

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
7/90 Annette Gatchett (513) 569-7697			radio-nuclides (NORM, LLRW, TRU)		precipitation	
EPA Demo American Creosote Works, FL 1991 Kim Lisa Kreiton (513) 569-7328	Membrane Separation	Groundwater	Removal: 90% PAH 80% creosote 25-30% smaller phenolics		Hyperfiltration unit	Clean H_20 t concen-trat contaminan holding tan
EPA Demo Palangana Uranium Mine Site, TX 7/93 Annette Gatchett (513) 569-7697	Precipitation/Filtrati on	Groundwater	Low-moderate levels of NORM (uranium, radium-226, thorium-230)	Complexing, adsorption, and absorption	URAL complexing agent	Treated wa holding pon
EPA Demo San Jose, CA 3/89 Norma Lewis (513) 569-7665	Ultraviolet radiation & oxidation	Groundwater	Halogenated hydrocarbons, VOCs, pesticides, PCBs - 99% TCE, 58% 1,1-DCA, 85% 1,1,1-TCA removal	UV, H_2O_2, and O_3 destruction	Tank with air compressor, O_3 generator, and H_2O_2 feed	Offgas to o destruction
DOE Demo Kansas City Plant, MO Sidney B. Garland II (615) 579-8581	Ultraviolet radiation, hydrogen peroxide, and ozone	Groundwater	TCE	30% downtime for maintenance and repair	Flow rate has averaged 15% of design rate	
DOI Demo Birmingham, AL Manassas, VA 1992	Solid/liquid separation	Wastewater	Solids and fine particulate matter in mining wastes	Feed flow rate in field test unit was 50-175 gpm. Freed material is usually a degradable polyacrylamide	Pipe delivery system used as mixing system to minimize quantity of feed used.	The "clean" can be disc Flocculated becomes s for a landfill

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TABLE 3-14
COMPLETED PROJECTS: EX SITU PHYSICAL/CHEMICAL TREATMENT FOR GROUNDWATER, SURFACE

(CONTINUED)

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
Ronald H. Church (205) 759-9446					Waste should be in slurry form	
DOI Demo Bureau of Mines and USAEC (Cooperative effort) Buffalo, NY Ronald H. Church (205) 759-9446	Solid/liquid separation	Wastewater	Suspended particulates from dredging wastes	Waste pumped through a 4-inch line to 1,000-gallon fiberglass mixing tank. 6-inch-by-2-inch static mixer.	Polymer used for flocculation is pumped through a 1-inch line to the mixing tank.	NTU values discharge w ranged from 17, with the underflow d containing a 31% solids
DOI Demo Salt Lake City Research Center K.S. Gritton (801) 584-4170	Treatment of copper industry waste	Slags, dusts, sludges, liquids	Copper byproducts - arsenic, heavy metals	Acid in refinery waste is used to solubilize metals in flue dust, with subsequent metal recovery	Ex situ	Vitrification arsenic sulf leaves a de reactive, gla material
EPA *SITE* Demo Selma Pressure Treating Selma, CA 11/90 Edward Bates (513) 569-7774	Solidification/Stabilization with silicate compounds	Groundwater, soil, sludge	Organics and inorganics	Silicate compounds	Pretreatment separation of coarse and fine materials	PCP leacha centrations up to 97%. Cu immobili

Sources: *Innovative Treatment Technologies: Annual StatusReport* (EPA, 1993).
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

✍ 3.12 OTHER TREATMENT TECHNOLOGIES FOR GROUNDWATER, SURFACE WATER, AND LEACHATE

Natural attenuation for groundwater is discussed in Section 4 (Treatment Technology Profile 4.50). Completed projects for other treatment technologies for groundwater, surface water, and leachate are shown in Table 3-15.

TABLE 3-15
COMPLETED PROJECTS: OTHER TREATMENTS FOR GROUNDWATER, SURFACE WATER, AND LEACHATE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Demo Kerr-McGee Chemical Corp., WI 1993 Douglas Grosse (513) 569-7844	Electrochemical reduction & immobilization	Groundwater	Hexavalent chromium and other heavy metals	In situ requires excess ferrous ions - maintain pH	Electrochemical reactions generate ions for removal of hexavalent chromium	Clean wate reinjected i ground
EPA Demo Palmerton Zinc Superfund Site, PA 1990 John Martin (513) 569-7758	Membrane microfiltration	Liquids & wastes	Solid particles in liquid - removal averages 99.95% Zn and TSS	Filter press 45 psi	Tyvek (T-980) spun-bound olefin filter	Filter cake solids
EPA Demo Casmalia, CA 1992 Douglas Grosse (513) 569-7844	Rochem disc tube module system	Aqueous solutions	Organics	1-2 gpm over 2-3 weeks	Membrane separation (reverse osmosis), ultrafiltration	Concentrate contaminan
EPA Demo Hamilton Harbor, Canada 1992 Gordon Evans (513) 569-7684	Thermal gas phase reduction	Soil, sludge, liquids, & gases	PCBs, PAHs, chlorophenols, pesticides	850 ?C or higher - 25 tons/day	Heated hydrogen reduction	
EPA Demo Burleigh Tunnel, CO 1991 Edward Bates (513) 569-7774	Wetlands-based treatment	Influent waters	Metals	Principal components - soils, microbial fauna, algae, and vascular plants	Natural processes - filtration, ion exchange, adsorption, absorption, and precipitation	
EPA Demo Ogden's Research Facility	Circulating bed combustor (CBC)	Soil, sludge, & liquids	Halogenated and nonhalogenated organic compounds,	16-inch diameter CBC, 1,450-1,600 ?F, waste feed <1 inch	Highly turbulent combustion zone	DRE value 99.99% for organics. T

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TABLE 3-15

COMPLETED PROJECTS: OTHER TREATMENTS FOR GROUNDWATER, SURFACE WATER, AND LEACHATE

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
San Diego, CA Douglas Grosse (513) 569-7844			PCBs			ash disposa
EPA *SITE* Demo Ogden Research Facility, San Diego, CA 3/89 Douglas Grosse (513) 569-7844	Circulating bed combustor	Soil, sludge, liquids, solids, & slurry	Halogenated and nonhalogenated organic compounds, PCBs, dioxin	Combustion through hot cyclone (1,450-1,600 ?F)	Mixing wastes. Limestone added to neutralize acid gases	Treated ash
DOE Integrated Demo, DOE Savannah River Site, Aiken, GA Terry Walton (803) 725-5218	Organics in soil and groundwater at nonarid sites	Soils, groundwater at nonarid sites, emphasizing in situ remediation	Volatile organics such as TCE and PCE	Integrated demo includes many technologies- no specific parameters given	Directional well drilling precedes the in situ air stripping	Offgas treat also being demonstrat
DOE Integrated Demo, 4 DOE sites: (1) Hanford (2) Fernald, ID (3) Oak Ridge (4) Savannah River 2/91 Roger Gilchrist (509) 376-5310	USTs, emphasizing the single-shell storage tanks located at the Hanford site	Groundwater, soil	Tank waste constituents ranging from Na-nitrates to transuranics, in 3 forms: supernatant (liquid), sludges, and saltcake (which can be as hard as cement)	UST-ID is pursuing technologies in two general areas: characterization/retrieval and separations/low-Level waste	Parameters vary among technologies	Parameters among tech
DOI Demo Bureau of Mines Tuscaloosa Research Center, AL C.W. Smith (205) 759-9460	Well Point Containment	Groundwater	Lead, iron	The Bureau of Mines demonstration included a 235-well point system and a monitoring well network	Well point system in conjunction with a french drain to contain impoundment leakage	Monitoring groundwate after well p pumping be

Sources: *Innovative Treatment Technologies: Annual Status Report* (EPA, 1993).

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TABLE 3-15

COMPLETED PROJECTS: OTHER TREATMENTS FOR GROUNDWATER, SURFACE WATER, AND LEACHATE

Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

✍ 3.13 AIR EMISSIONS/OFF-GAS TREATMENT

A number of technologies have been widely applied for removal of VOCs from off-gas streams; however, the application of these technologies to off-gases from site remediation may be quite limited. Biofiltration has been widely applied for VOC destruction in Europe and Japan, but it has only recently been used in the United States. Catalytic and thermal oxidation are widely used for the destruction of gas-phase VOCs in U.S. industry, yet have only limited applications to site remediation of off-gases. Vapor phase carbon adsorption has been the VOC removal technology most commonly used for site remediation off-gases. Carbon adsorption, however, does not destroy the VOCs so that additional destruction or disposal is required. The following factors may affect the effectiveness and cost of the various technologies: VOC concentration, VOC species, presence of halogenated VOCs, presence of catalyst poisons, particulate loading, moisture content, gas flow rate, and ambient temperature.

Available air emissions/off-gas treatment technologies include biofiltration, high energy corona, membrane separation, oxidation, and vapor phase carbon adsorption. These processes are discussed in Section 4 (Treatment Technology Profiles 4.51 through 4.55). Completed air emissions/off-gas treatment projects are shown in Table 3-16.

TABLE 3-16
COMPLETED PROJECTS: AIR EMISSIONS/OFF-GAS TREATMENT

Site Name/Contact	Technology/ Vendor	Media Treated	Contaminants Treated	Operating Parameters	Materials Handling	Resid Manage
EPA Demo 1989 Ronald Lewis (513) 569-7856	Chemtact? gaseous waste treatment	Gaseous wastestreams	Organic and inorganics 85-100% removal of hydrocarbons 94% removal of phenol and formaldehyde	Once through system with droplet size less than 10 microns and a longer retention time	Gas scrubber	Low vdume liquid conde
EPA Demo Hamilton Harbor, Canada 1992 Gordon Evans (513) 569-7684	Thermal gas phase reduction	Soil, sludge, liquids, & gases	Organics and chlorinated organics	850 ?C or higher	Hydrogen reduces organics to smaller lighter hydrocarbons.	Gas stream
DOE Integrated Demo DOE Hanford Reservation Steve Stein (206) 528-3340	VOC compounds at arid sites	Arid zones or environments with large vadose zones	VOCs (TCE, PCE)	Integrated demo includes many technologies- no specific parameters given	Integrated demo includes many technologies- no specific parameters given	Integrated c includes ma technologie specific par given

Sources: *Innovative Treatment Technologies: Annual Status Report* (EPA, 1993).
Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993).

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4.1 BIODEGRADATION (IN SITU)

Description: Biodegradation is a process in which indigenous or inoculated micro organisms (i.e., fu microbes) degrade (metabolize) organic contaminants found in soil and/or groundwater. In t oxygen (aerobic conditions), microorganisms will ultimately convert many organic contami water, and microbial cell mass. In the absence of oxygen (anaerobic conditions), the contan metabolized to methane, limited amount of carbon dioxide, and trace amounts of hydrogen ga nants may be degraded to intermediate products that may be less, equally, or more h az contaminant. For example, TCE anaerobically biodegrades to the persistent and more toxic such problems, most biodegradation projects are conducted in situ.

4-1 TYPICAL IN SITU BIODEGRADATION SYSTEM

The in situ bioremediation of soil typically involves the percolation or injection of groundv water mixed with nutrients and saturated with dissolved oxygen. Sometimes accl (bioaugmentation) and/or another oxygen source such as hydrogen peroxide are also added. spray irrigation is typically used for shallow contaminated soils, and injection wells are used soils.

Applicability: Bioremediation techniques have been successfully used to remediate soils, sludges, and groundv

petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. F effectiveness of microbial degradation of nitrotoluenes in soils contaminated with explosives. Bio effective for remediating low level residual contamination in conjunction with source removal.

While bioremediation cannot degrade inor gaic contaminants, bioremediation can be used to ch inorganics and cause adsorption, uptake, accumulation, and concentration of inorganics in m These techniques, while still largely experimental, show consid erable promise of stabilizing from soil.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Cleanup goals may not be attained if the soil matrix prohibits contaminant-microorgani
- The circulation of water-based solutions through the soil may increase contaminant treatment of underlying groundwater.
- Preferential colonization by microbes may occur causing clogging of nutrient and water
- Preferential flow paths may severely decrease contact between injected fluids and cont contaminated zones. The system should not be used for clay, highly layered, or h environments because of oxygen (or other electron acceptor) transfer limitations.
- High concentrations of heavy metals, highly chlorinated organics, long chain hydroca are likely to be toxic to microorganisms.
- Bioremediation slows at low temperat ures.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requiren and Sludge). Important contaminant characteristics that need to be identified in a b investigation are their potential to leach (e.g., water solubility and soil sorption coefficient); (e.g., tendency toward nonbiological reactions, such as hydrolysis, oxidation, and poly importantly, their biodegradability.

Soil characteristics that need to be determined include the depth and areal extent of contaminat

the contaminants; soil type and properties (e.g., organic content, texture, pH, permeability, moisture content, and nutrient level); the competition for oxygen (i.e., redox potential); the substances that are toxic to microorganisms; and the ability of microorganisms in the soil to de

Treatability or feasibility tests are performed to determine whether bioremediation is feasible the remediation time frame and parameters. Field testing can be performed to determine the well spacing.

Performance Data:

The main advantage of the in situ process is that it allows soil to be treated with out being ex resulting in less disturbance of site activities and significant cost savings over methods i transportation. Also, both contaminated ground water and soil can be treated simultaneously, advantages. In situ processes generally require longer time periods, however, and there is uniformity of treatment because of the inherent variability in soil and aquifer charact monitoring progress.

Remediation times are often years, depending mainly on the degrada tion rates of sp characteristics, and climate. Less than 1 year may be required to clean up some contamina weight compounds take longer to degrade.

There is a risk of increasing contaminant mobility and leaching of contaminants into the g often do not accept the addition of nitrates or non-native microorganisms to contaminated soil has been selected for remedial and emergency response actions at only a few Superfund site hydrocarbons can be readily bioremediated, at relatively low cost, by stimulating indigenous without nutrients.

Cost:

Typical costs for in situ bioremediation range from $30 to $100 per cubic meter ($20 to $80 Variables affecting the cost are the nature and depth of the contaminants, use of bio augm peroxide addition, and groundwater pumping rates.

References:

Aggarwal, P.K., J.L. Means, R.E. Hinchee, G.L. Headington, and A.R. Gavaskar, July 1 *Chemicals for In-Situ Biodegradation of Fuel Hydrocarbons,* Air Force Engineering & Servi FL.

Arthur, M.F., T.C. Zwick, G.K. O'Brien, and R.E. Hoeppel, 1988. "Laboratory Studies Mediated In-Situ Soil Remediation," in *1988 DOE Model Conference Proceedings,* Vol. 3, A14/MF A01, as cited in *Energy Research Abstracts*, EDB-89:134046, TIC Accession No. D

EPA, 1993. *Augmented In-Situ Subsurface Bioremediation Process, Bio-Rem, Inc.*, EP Bulletin, EPA/540/MR-93/527.

EPA, 1994. *Ex-Situ Anaerobic Bioremediation System, Dinoseb, J.R. Simplot Company*, EI Bulletin; EPA/540/MR-94/508.

Wetzel, R.S., C.M. Durst, D.H. Davidson, and D.J. Sarno, July 1987. *In-Situ Biological Tr Force Base, Volume II: Field Test Results and Cost Model,* AD-A187 486, Air Force Engin Tyndall AFB, FL.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Naval Communi-cation Station, Thurso, Scotland	Deh Bin Chan, Ph.D. NFESC Code 411 Port Hueneme, CA 93043 (805) 982-4191, DSN 551-4191	Oil degrading bacteria applied by injection wells and surface sprayers to hard to reach areas where indigenous bacteria had been destroyed.	1,000 ppm COD in leaching water from beach before entering bioreactor	80% removal (60% in situ, 20% bio-reactor)	$30/ton of soil
DOE, Savannah River, SC	Terry Hazen Westinghouse Savannah River Company P.O. Box 616 Building 773-42A Aiken, SC 29802 (803) 725-6413	Plants (lobolly pine) are cultivated to encourage root-associated (rhizosphere) microorganisms to degrade contaminants. TCE and PCE targeted.	Not currently funded	NA	<$50,000/acre
FAA Technical Center-Area D Atlantic County, NJ	Carla Struble (212) 264-4595	Pilot scale completed August 1992. Nutrient addition and groundwater reinjection in saturated soil (sand)	33,000 yd^3 Jet fuel NAPLs	New Jersey soil action levels	Expected full scale $286K CAP and $200K O&M
Eglin AFB, FL	Alison Thomas (904) 283-6303	Using nitrate as an alternative electror	4,000 ppb BTEX		

		acceptor to enhance anaerobic biodegradation of a fuel-contaminated aquifer.		NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Ron Hoeppel	NFESC	(805) 982-1655 DSN 551-1655	Code 411 Port Hueneme, CA 93043
John Matthews	EPA-RSKERL	(405) 436-8600	P.O. Box 1198 Ada, OK 74821
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.2 BIOVENTING

Description: Bioventing is a promising new technology that stimulates the natural in situ biodegradation of in soil by providing oxygen to existing soil microorganisms. In contrast to soil vapor vacuu uses low air flow rates to provide only enough oxygen to sustain microbial activity. Ox supplied through direct air injection into residual contamination in soil, as illustrated below. I of adsorbed fuel residuals, volatile compounds are biodegraded as vapors move slowly throug

4-2 TYPICAL BIOVENTING SYSTEM

The AFCEE bioventing initiative is demonstrating that this technology is effective under widel

Initial testing has been completed at 117 sites, with more than 90 pilot systems now installations. On smaller sites, many of these single-well pilot systems are providing full-scale

Regulatory acceptance of this technology has been obtained in 30 states and in all 10 EPA re technology in the private sector is growing rapidly following USAF leadership.

Applicability: Bioventing techniques have been successfully used to remediate soils contaminated by p nonchlorinated solvents, some pesticides, wood preservatives, and other organic chemicals.

While bioremediation cannot degrade inorganic contaminants, bioremediation can be used to of inorganics and cause adsorption, uptake, accumulation, and concentration of i macroorganisms. These techniques, while still largely experimental, show considerable p removing inorganics from soil.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Pilot-scale, in situ tests should be conducted to determine soil gas permeability.
- The water table within several feet of the surface, saturated soil lenses, or low p bioventing performance.
- Vapors can build up in basements within the radius of influence of air injection wel alleviated by extracting air near the structure of concern.
- Low soil moisture content may limit biodegradation and the effectiveness of bioventing the soils.
- Monitoring of off-gases at the soil surface may be required.
- Aerobic biodegradation of many chlorinated compounds may not be effective unless present, or an anaerobic cycle.
- Low temperatures slow remediation.

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requiren and Sludge). Two basic criteria must be satisfied for successful bioventing. First, air must b soil in sufficient quantities to maintain aerobic conditions; second, natural hydrocarbon-d must be present in concentrations large enough to obtain reasonable biodegradation rates. Init determine both air permeability of soil and in situ respiration rates.

Soil grain size and soil moisture significantly influence soil gas permeability. Perhaps the permeability is excessive soil moisture. A combination of high water tables, high moisture, a made bioventing infeasible at some AFCEE test locations.

Several soil characteristics that are known to impact microbial activity are pH, moisture, and phosphorus, and temperature. Soil pH measurements show the o ptional pH range to be 6 to however, microbial respiration has been observed at all sites, even in soils that fall out Optimum soil moisture is very soil-specific because too much moisture can reduce the a ir pe decrease its oxygen transfer capability. Too little moisture will inhibit microbial activity. Se test sites have sustained biodegradation rates with moisture levels as low as 2 to 5% by weight

Biological activity has been measured at Eielson AFB, Alaska, in soil temperatures as low more rapidly degrade contaminants during summer months, but some remediation occurs in so 0 ?C.

Performance Data:

Bioventing is becoming more common, and most of the hardware components are readily a receiving increased exposure to the remediation consulting community, particularly its use vapor extraction (SVE). AFCEE is sponsoring bioventing demonstrations at 135 sites. technologies, the time required to remediate a site using bioventing is highly dependent up chemical properties of the contaminated media.

Using an approach similar to the AFCEE Bioventing Initiative (138 sites at 48 military coordination with the regulatory community, plans to conduct a multiple site application of the

Bioslurping is an approach adapted from the vacuum dewatering industry. A bioslurper sys tube that extends into the LNAPL free product layer in the well. Product is drawn into the tube toward the vacuum extraction pump. Product is drawn u p the tube in the form of a

vapor, and/or a film. Product can be drawn up the tube as a solid column, provided that the pr fast enough and the depth below the ground surface does not exceed roughly 25 feet be Otherwise, the product is "slurped" up the well through entrainment. Recovery of pro conventional methods because, as opposed to gravity alone, the vacuum provides a drivir proceeds along a horizontal flow path, which reduces product entrapment or "smearing" typica In addition, as vapor is extracted from the subsurface, oxygen, in the form of air, promote (a.k.a. bioventing) throughout the affected vadose zone and capillary fringe.

Cost: Based on AFCEE and commercial applications of this technology, costs for operating a biover $10 to $70 per cubic meter ($10 to $50 per cubic yard). Factors that affect the cost o f biove type and concentration, soil permeability, well spacing and number, pumping rate, and technology does not require expensive equipment and can be left unattended for long periods personnel are involved in the operation and maintenance of a bioventing system. Typical monitoring is conducted.

References:

AFCEE, 1994. *Bioventing Performance and Cost Summary*, Draft. Brooks AFB, TX.

Aggarwal, P.K., J.L. Means, R.E. Hinchee, G.L. Headington, and A.R. Gavaskar, July 1 *Chemicals for In-Situ Biodegradation of Fuel Hydrocarbons,* Air Force Engineering & Servi FL.

DOE, 1993. *Methanotrophic In Situ Bioremediation Using Methane/Air and Gaseou Horizontal Wells,* Technology Information Profile, Rev. 2, DOE ProTech Database, TTP Refe

Hinchee, R.E., S.K. Ong, and R. Hoeppel, 1991. "A Treatability Test for Bioventing," in *Annual Meeting and Exhibition, Air and Waste Management Association,* Vancouver, BC, 91

Hinchee, R.E., S.K. Ong, R.N. Miller, and D.C. Downey, 1992. Report to AFCEE, Brooks A

Hinchee, R.E., 1993. "Bioventing of Petroleum Hydrocarbons," *Handbook of Bioremedic* Boca Raton, FL, pp. 39-59.

Hoeppel, R.E., R.E. Hinchee, and M.F. Arthur, 1991. "Bioventing Soils Contaminated with P *J. Ind. Microbiol.,* 8:141-146.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Savannah River	DOE Program Manager Kurt Gerdes EM-551, Trevion II Washington, DC 20585 (301) 903-7289	Disposal of solvents used to degrease nuclear fuel target elements. Contamination is mostly TCE and PCE.	Soil: 10 ppm GW: 1 ppm	<2 ppb	Capital: $150K + 200 man-hours per week
Tyndall AFB, FL	Armstrong Laboratory/EQW 139 Barnes Drive Tyndall AFB, FL 32403 (904) 283-6208 DSN: 523-6208	Pilot-scale field test for volatile hydrocarbons in vadose zone.	>1,000 mg TPH/kg soil	<30 mg TPH/kg soil	$15-$20/m^3 ($12-$15/yd^3)
Eielson AFB, AK	Armstrong Laboratory/EQW Kathy Vogel 139 Barnes Drive Tyndall AFB, FL 32403 (904) 283-6208	Pilot-scale field test comparison of enhanced solar, active, and buried heat tape warming methods.	Volatile Hydro-carbons	Expected 11/94	Average bioventing cost $10-$15/yd^3
Hill AFB, UT	AFCEE DSN: 240-4331	25,000 gallons of JP-4 spill to a depth of 60 ft	20,000 ppm TPH	98% reduction	Average bioventing cost $10-$15/yd^3

Points of Contact:

Contact	Government Agency	Phone	Location
Greg Sayles	EPA RREL	(513) 569-7328	26 West. M.L. King Dr. Cincinnati, OH 45268
Lt. Col. Ross N. Miller or Patrick E. Haas	AFCEE/ERT	(210) 536-4331 Fax: (210) 536-4330	8001 Arnold Drive Brooks AFB, TX 78235
Mark Zappi or Douglas Gunnison	USAE-WES	(601) 636-2856 Fax: (610)634-3833	Attn: CEWES-EE-S 3909 Halls Ferry Road Vicksburg, MS 39180-6199
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401
Ronald Hoeppel	NFESC	(805) 982-1655	Code ESC 411 5600 Center Drive Port Hueneme, CA 930434328

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4.3 WHITE ROT FUNGUS

Description: Because of its lignin-degrading or wood-rotting enzymes, white rot fungus has been reported t of organopollutants. Two different treatment configurations have been tested for white bioreactor. An aerobic system using moisturized air on wood chips is used in a reactor for bi was used in the bench-scale trial of the process. In the pilot-scale project, an adjustable shred chips for the open system. The open system is similar to composting, with wood chips on a surface that is covered. Temperature is not controlled in this type of system. The op biodegradation with lignin-degrading fungus ranges from 30 to 38 ?C (86 to 100 ?F). The h reaction will help to maintain the temperature of the process near the optimum.

4-3 TYPICAL WHITE ROT FUNGUS BIODEGRADATION PROCESS

Although white rot fungus degradation of TNT has been reported in laboratory-scale settin number of factors increase the difficulty of using this technology for full-scale remediatio competition from native bacterial populations, toxicity inhibition, chemical sorption, and t based cleanup levels. White rot works best in nitrogen-limited environments.

In bench-scale studies of mixed fungal and bacterial systems, most of the reported degradatic to native bacterial populations. High TNT or PCP concentrations in soil also can inhibit grow study suggested that one particular species of white rot was incapable of growing in soils cont more of TNT. In addition, some reports indicate that TNT losses reported in white rot fungus to adsorption onto the fungus and soil amendments, such as corn cobs and straw, rather th TNT. Alleman (1991) tested a variety of white rot fungus for PCP sensitivity. Eighteen sensitivity were inhibited by 10 mg of PCP per liter when grown on agar plates. Within 2 we grew in the inhibition zones. In liquid-phase toxicity experiments, all 18 species were killed b

Applicability: White rot fungus has the ability to degrade and mineralize a number of organopollutants in conventional explosives TNT, RDX, and HMX. In addition, white rot fungus has the potential t other recalcitrant materials, such as DDT, PAH, PCB, and PCP[2-4].

Limitations: The following factors may limit the applicability and effectiveness of the process:

- High TNT concentrations in the soil, sediment, or sludge.
- The degradation of contaminants not being sufficient to meet cleanup levels.
- Competition from native bacterial populations, toxicity inhibition, and chemical sorptio

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requiren and Sludge). Subsection 2.7.1 provides a general overview of explosives in soils, sediment data required to evaluate the white rot process include:

- Explosives concentration of the contaminated soil, sludge, or sediment.
- Final explosive levels required after treatment.
- Other contaminants present.
- Characterization of soil properties.

Performance

Data: This technology has been known for approximately 20 years with very few, if any, commerc scale treatability study was conducted using white rot fungus at a former ordnance open burn Site D, Naval Submarine Base, Bangor, Washington. Initial TNT concentrations of 1,844 ppm ppm in 30 days and 1,087 ppm in 120 days. The overall degradation was 41%, and final T above the proposed cleanup level of 30 ppm. Additional studies to evaluat e the effectivenes explosives-contaminated soil are being sponsored by USAEC.

White rot fungus is not native to soil, and some forms of bacteria may become predominant c In addition, little is known of th e ability of the white rot to compete with other forms of fungi. laboratory studies cited use sterile conditions, which allow the white rot fungus to grow with encountered in field sites.

Experiments indicate that white rot fungus is viable under specific environmental condit conditions in actual site testing may optimize the ability of white rot fungus to remediate haz timeframe and cost effectiveness of dupli cating these conditions have never been taken into a are widely believed to optimize the viability and potential of white rot fungus. First, secretio in nutrient-deficient conditions. The optimum concentrat ion of nitrogen is around 2 to 4 ml concentrations of oxygen results in ligninolytic action but not to the same degree as 100% mineralization is two- to three-fold greater under 100% oxygen. A concentration of ox yge enzymatic action. Third, pH has been determined to be optimal around 4.5. Fourth, the opt between 40 and 45%.

Cost: The costs are estimated at $98 per cubic meter ($75 per cubic yard).

References:

Alleman, B. 1991. *Degradation of Pentachlorophenol by Selected Species of White* University of Arizona.

Bumpus, J.A., and S.D. Aust, 1985. "Studies on the Biodegradation of Organopollutants by *Proceedings of the International Conference on New Frontiers for Hazardous Waste Mana* 1985, Pittsburgh, PA, pp. 404-410, EPA/600/9-85/025.

EPA, 1993. *Fungal Treatment Technology,* EPA RREL, Demonstration Bulletin, EPA/540/M

Janshekar, H. and Fiechter A., 1988. "Cultivation of P. Chrysosporium and Production

Submerged Stirred Tank Reactors," *Journal of Biotechnology,* 8:97-112.

Lamar, Richard T. and Dietrich D.M., 1990. "In Situ Depletion of Pentachlorophenol fro Phanerochaete Species," *Applied Environmental Microbiology,* 56, 3093.

Lamar, Richard T. and Richard J. Scholze, 4-6 February 1992. *White-Rot Fungi Biodeg Ammunition Boxes,* Presented at the Natio nal Research and Development Conference on th Materials, San Francisco, CA.

Lebron, C.A., June 1990. *Ordnance Bioremediation - Initial Feasibility Report,* NCEL.

Lebron, C.A., L.A. Karr, T. Fernando, and S.D. Aust, 1992. *Biodegradation of 2,4,6-Trin Fungus,* U.S. Patent Number 5,085,998.

Scholze, R.J., R.T. Lamar, J. Bolduc, and D. Dietrich, 1994. *Feasibility of White Rot Fun PCP-Treated Ammunition Boxes,* USACERL Technical Report.

Venkatadri, R., S. Tsai, N. Vukanic, and L.B. Hein, 1992. "Use of Biofilm Membrane Reac Lignin Peroxidase and Treatment of Pentachlorophenol by Phanerochaete Chrysosporium, *Hazardous Materials,* Vol. 9, pp. 231-243.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Letterkenny AD Chambersburg, PA	Richard Scholze USACERL P.O. Box 9005 Champaign, IL 618269005 (217) 373-3488	Pilot-scale demonstration using PCP-treated ammunition boxes in less than ideal conditions.	425 ppm of PCB	30% removal but 80% removal in lab	NA
Brookhaven Wood Preserving, MA	Richard Lamar Forest Products Lab., USDA (608) 231-9469 John Glasser EPA RREL (513) 569-7568	White rot fungi to treat chlorinated VOCs and PAHs. Treatability Study in 1991. Full demo in 1993.	PCP 700 ppm	89% PCP removal 70% PAH removal	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Explosives: Carmen A. Lebron	NFESC	(805) 982-1616 Autovon 551-1616	ESC 411 Port Hueneme, CA 93043
Other Contaminants Richard Scholze	USACE-CERL	(217) 373-3488 (217) 352-6511 (800) USA-CERL	P.O. Box 9005 Champaign, IL 61826-9005
John Glasser	EPA RREL	(513) 569-7568 Fax: (513) 569-7676	26 West M.L. King Drive Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.4 PNEUMATIC FRACTURING

Description: Pneumatic fracturing (PF) is an enhancement technology designed to increase the effi technologies in difficult soil conditions. PF injects pressurized air beneath the surface tc permeability and over-consolidated sediments. These new passageways increase the effec processes and enhance extraction efficiencies by increasing contact between contaminants ads and the extraction medium.

4-4 TYPICAL PNEUMATIC FRACTURING PROCESS

In the PF process, fracture wells are drilled in the contaminated vadose zone and left open (ur depth. A packer system is used to isolate small (0.6-meter or 2-foot) intervals so that short compressed air (less than 10,300 mmHg or 200 pounds per square inch) can be injected into tl formation. The process is repeated for each interval. The fracturing extends and enlar introduces new fractures, primarily in the horizontal direction. When fracturing has been co then subjected to vapor extraction, either by applying a vacuum to all wells or by extracting f

other wells are capped or used for passive air inlet or forced air injection.

Applicability: PF is applicable to the complete range of contaminant groups with no particular target group. primarily to fracture silts, clays, shale, and bedrock.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- The technology should not be used in areas of high seismic activity.
- Fractures will close in non-clayey soils.
- Investigation of possible underground utilities, structures, or trapped free product is requ
- The potential exists to open new pathways for the unwanted spread of contaminants phase liquids).

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requiren and Sludge). Soil characteristics that need to be determined include the depth and areal exte concentration of the contaminants, and soil type and properties (e.g., structure, organic conte water-holding capacity, and moisture content).

Performance Data: The technology is currently available from only one vendor. PF was tested with hot gas in EPA's SITE demonstration program in 1992. Results indicate that PF increased the eff influence nearly threefold and increased the rate of mass removal up to 25 times over th conventional extraction technologies. A Phase II demonstration is planned for 1994. T demonstrated in the field, including the one under EPA's SITE program. In addition, nu theoretical studies have been published.

During summer 1993, a pilot demonstration of pneumatic fracturing was sponsored by DOE a remediation of the fine-grained silts, clays, and sedimentary rock that underlie the site. At or fuel oil was being pumped from existing recovery wells, pneumatic fracturing increased the a rate by 15 times. Tests conducted in the unsaturated zone also showed enhanced air per fracturing, ranging from 5 to 30 times greater than prefracture values.

Normal operation employs a two-person crew, making 15 to 25 fractures per day with a
meters (15 to 20 feet) to a depth of 15 to 30 meters (50 to 100 feet). For longer remediatior
efforts may be required at 6- to 12-month intervals.

Cost: The approximate cost range for pneumatic fracturing is $9 to $13 per metric ton ($8 to $12 pe

References:

EPA, 1993. *Accutech Pneumatic Fracturing Extraction and Hot Gas Injection, Pha*
includes Technology Evaluation, EPA/540/R-93/509; Technology Demonstration Summar
Demonstration Bulletin, EPA/540/MR-93/509; and Applications Analysis, EPA/540/AR-9

EPA, 1993. "Pneumatic Fracturing Increases VOC Extractor Rate," *Tech Trends*, E
93/010.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Hillsborough, NJ	John Liskowitz Accutech Remedial Systems, Inc. (908) 739-6444 Fax: (908) 739-0451	PF and hot gas injection increased SVE flow rate by more than 600%.	NA	NA	$308/kg ($140/lb) TCE removed
Marcus Hook, PA	John Schuring or Peter Lederman Hazardous Substance Management Research Center at New Jersey Institute of Technology 138 Warren Street Newark, NJ 07102 (201) 596-5849/2457	Pilot-scale testing of PF and bioremediation. Completion due in July 1994.	NA	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Uwe Frank	EPA	(908) 321-6626	EPA, Building 10, MS-104 2890 Woodbridge Avenue Edison, NJ 08837
Clyde Frank	DOE	(202) 586-6382	DOE Environmental Restoration/Waste Management, EM-50 1000 Independence Ave. Washington, DC 20585
Dan Hunt	USAF	(405) 734-3058	Environmental Management Directorate OC-ALC/EM Tinker AFB, OK 73145
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.5 SOIL FLUSHING

Description: In situ soil flushing is the extraction of contaminants from the soil with water or other suitable flushing is accomplished by passing the extraction fluid through in-place soils using an injecti Extraction fluids must be recovered from the underlying aquifer and, when possible, they are r

4-5 TYPICAL SOIL FLUSHING SYSTEM

Recovered groundwater and flushing fluids with the desorbed contam inants may need treatı

discharge standards prior to recycle or release to local, publicly owned wastewater treatn streams. To the maximum extent practical, recovered fluids should be reused in the flushing of surfactants from recovered flushing fluid, for reuse in the process, is a major factor in Treatment of the recovered fluids results in process sludges and residual solids, such as spe exchange resin, which must be appropriately treated before disposal. Air emissions of vo recovered flushing fluids should be collected and treated, as appropriate, to meet applicat Residual flushing additives in the soil may be a concern and should be evaluated on a site -spe

Applicability: The target contaminant group for soil flushing is inorganics including radioactive contaminants. Th to treat VOCs, SVOCs, fuels, and pesticides, but it may be less cost-effective than alternativ contaminant groups. The addition of compatible surfactants may be used to increase the effective s compounds; however, the flushing solution may alter the physical/chemical properties of the soil offers the potential for recovery of metals and can mobilize a wide range of organic and inorganic co grained soils.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Low permeability soils are difficult to treat.
- Surfactants can adhere to soil and reduce effective soil porosity.
- Reactions of flushing fluids with soil can reduce contaminant mobility.
- The potential of washing the contaminant beyond the capture zone and the introducti subsurface concern regulators. The technology should be used only where flushe flushing fluid can be contained and recaptured.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requiren and Sludge). Treatability tests are required to determine the feasibility of the specific so considered. Physical and chemical soil characterization parameters that should be permeability, soil structure, soil texture, soil porosity, moisture content, total organic carbon capacity (CEC), pH, and buffering capacity.

Contaminant characteristics that should be established include concentration, solubility, parti

products, reduction potential, and complex stability constants. Soil and contaminant characte
flushing fluids required, flushing fluid compatibility, and changes in flushing fluids with chan

Performance Data:

Soil flushing is a developing technology that has had limited use in the United States. Typic
treatability studies must be performed under site-specific conditions before soil flushing is s
choice. To date, the technology has been selected as part of the source control remedy at 1
technology is currently operational at only one Superfund site; a second was scheduled to b
EPA completed construction of a mobile soil-flushing system, the In Situ Contaminant/Treat
mobile soil-flushing system is designed for use at spills and uncontrolled hazardous waste sit
little commercial success with this technology.

Cost:

Not available.

References:

EPA, 1991. *In Situ Soil Flushing*, Engineering Bulletin, EPA/540/2-91/021.

Nash J., R.P. Traver, and D.C. Downey, 1986. *Surfactant-Enhanced In Situ Soils Washing*
Services Laboratory, Florida. ESL-TR-97-18, Available from NTIS, Springfield, VA, Order

Sturges, S.G., Jr., P. McBeth, Jr., R.C. Pratt, 1992. "Performance of Soil Flushing and Grou
United Chrome Superfund Site," *Journal of Hazardous Materials*, El Savior Science Pub., E
pp. 59-78.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Laramie Tie Plant, WY	NA	Primary oil recovery to remove creosote contamination.	Total extractable organics = 93,000 mg/kg	4,000 ppm	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Michael Gruenfeld	EPA, Releases Control Branch, RREL	FTS 340-6625 or (908) 321-6625	2890 Woodbridge Avenue Building 10 Edison, NJ 08837
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.6 SOIL VAPOR EXTRACTION (IN SITU)

Description: Soil vapor extraction (SVE) is an in situ unsaturated (vadose) zone soil remediation technolo applied to the soil to induce the controlled flow of air and remove volatile and some semivolatil soil. The gas leaving the soil may be treated to recover or destroy the contaminants, dependi discharge regulations. Vertical extraction vents are typically used at depths of 1.5 meters (5 been successfully applied as deep as 91 meters (300 feet). Horizontal extraction vents horizontal borings) can be used as warranted by contaminant zone geometry, drill rig acce factors.

4-6 TYPICAL IN SITU SOIL VAPOR EXTRACTION SYSTEM

Groundwater depression pumps may be used to reduce groundwater upwelling in duced by t the depth of the vadose zone. Air injection is effective for facilitating extraction of deep conta in low permeability soils, and contamination in the saturated zone (see Treatment Techr Sparging).

Applicability: The target contaminant groups for SVE are VOCs and some fuels. The technology is typically a

compounds with a Henry's law constant greater than 0.01 or a vapor pressure greater than 0.5 n
Other factors, such as the moisture content, organic content, and air permeability of the soil,
effectiveness. SVE will not remove heavy oils, metals, PCBs, or dioxins. Because the process invo
of air through the soil, however, it often promotes the in situ biodegradation of low -volatility organi
present.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Soil that is tight or has high moisture content (>50%) has a reduced permeability
vacuums (increasing costs) and/or hindering the operation of SVE.

- Large screened intervals are required in extraction wells for soil with highly va
horizonation, which otherwise may result in uneven delivery of gas flow from the contan

- Soil that has high organic content or is extremely dry has a high sorption capacity of
reduced removal rates.

- Air emissions may require treatment to eliminate possible harm to the public and the env

- As a result of off-gas treatment, residual liquids and spent activated carbon may require

- SVE is not effective in the saturated zone; however, lowering the water table can exp
(this may address concerns regarding LNAPLs).

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requiren
and Sludge). Data requirements include the depth and areal extent of contamination, t
contaminants, depth to water table, and soil type and properties (e.g., structure, texture, pe
content).

Pilot studies should be performed to provide design information, including extraction well, radi
rates, optimal applied vacuum, and contaminant mass removal rates.

Performance Data: A field pilot study is necessary to establish the feasibility of the method as well as to obtain

design and configure the system. During full-scale operation, SVE can be run intermittently the extracted mass removal rate has reached an asymptotic level. This pulsed op eratio effectiveness of the system by facilitating extraction of higher concentrations of contaminants are removed by SVE, other remedial measures, such as biodegradation, can be investig objectives have not been met. SVE projects are typically completed in 18 months.

Cost: The cost of SVE is site-specific, depending on the size of the site, the nature and amount o hydrogeological setting (EPA, July 1989). The se factors affect the number of wells, the blov level required, and the length of time required to remediate the site. A requirement for significantly to the cost. Water is also frequently extracted during the process and usually r disposal, further adding to the cost. Cost estimates for SVE range between $10 and $50 per c per cubic yard) of soil. Pilot testing typically costs $10,000 to $100,000.

References:

EPA, 1989. *Terra Vac, In Situ Vacuum Extraction System*, EPA RREL, Applications Analysi EPA Report EPA/540/A5-89/003.

EPA, 1989. *Terra Vac — Vacuum Extraction*, EPA RREL, series includes Technology Evalu 89/003a, PB89-192025; Technology Evaluation, Vol. II, EPA/540/A5-89/003b; Application 89/003; Technology Demonstration Summary, EPA/540/S5-89/003; and Demonstration 89/003.

EPA, 1990. *State of Technology Review: Soil Vapor Extraction System Technology,* Haza Research Laboratory, Cincinnati, OH, EPA/600/2-89/024.

EPA, 1991. *AWD Technologies, Inc. — Integrated Vapor Extraction and Stream Vacuu* series includes Applications Analysis, EPA/540/A5-91/002, PB89-192033, and Demonstratio 89/003.

EPA 1991. *Guide for Conducting Treatability Studies Under CERCLA: Soil Vapor Extrac* DC, EPA Report EPA/540/2-91/019A.

EPA, 1991. *In-Situ Soil Vapor Extraction Treatment*, Engineering Bulletin, RREL, Cin 91/006.

EPA, 1991. *Soil Vapor Extraction Technology Reference Handbook*,EPA, RREL, Cincinnat
J.T. Curtis, Editors, EPA/540/2-91/003.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
DOE, Savannah River, Aiken, SC	Brian B. Looney Westinghouse Savannah River Co. P.O. Box 616 Aiken, SC 29802 (803) 725-3692	Horizontal wells are concurrently used to remediate soils and groundwater.	1,800 ppb TCE	30 ppb TCE	Demo — $44/kg Prep — $300,000-$450,000
Groveland Wells Superfund Site Groveland, MA	Mary Stinson EPA Technical Support Branch, RREL 2890 Woodbridge Ave. Building 10 Edison, NJ 08837-3679 (908) 321-6683 Terra Vac (714) 252-8900	Pilot system	3-350 ppm TCE	Non-detect to 39 ppm TCE	$30 to $75 per metric ton ($30 to $70 per ton) of soil
Hill AFB, UT	Major Mark Smith USAF	Full-scale system at JP-4 jet fuel spill site	NA	NA	NA
Letterkenny AD Chambersburg, PA	USAEC ETD Bldg. 4435 APG, MD 21010 (410) 671-2054	Large-scale (>50 vents) pilot system. 1,530 m^3 (2,000 yd^3) treated.	> 1,000 ppm total VOCs	NA	$2M design, install, and operation.

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Mike O'Rear	DOE Savannah River	(803) 725-5541	Aiken, SC
Ramon Mendoza	EPA Region IX	(415) 744-2410	75 Hawthorne Street San Francisco, CA 94105
Arthur L. Baehr	USGS	(609) 771-3978	810 Bear Tavern Rd., Suite 206 West Trenton, NJ 08628
Michael Gruenfeld	EPA Releases Control Branch, RREL	(908) 321-6625	2890 Woodbridge Ave. MS-104 Edison, NJ 08837-3679
Stacy Erikson	EPA	(303) 294-1084	One Denver Place

			999 18th Street Denver, CO 80202-2466
Major Mark Smith	USAF	(904) 283-6126	AL/EQW Tyndall AFB, FL 32403
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401
Mary K. Stinson	EPA Technical Support Branch, RREL	(908) 321-6683	2890 Woodbridge Ave MS-104 Edison, NJ 08837-3679

4.7 SOLIDIFICATION/STABILIZATION (IN SITU)

Description: Solidification/stabilization (S/S) reduces the mobility of hazardous substances and contami through both physical and chemical means. Unlike other remedial technologies, S/S seek contaminants within their "host" medium (i.e., the soil, sand, and/or building materials that c removing them through chemica l or physical treatment. Leachability testing is typically p immobilization of contaminants. In situ S/S techniques use auger/caisson systems and inject S/S agents to in situ soils.

4-7 TYPICAL AUGER/CAISSON AND REAGENT/INJECTOR HEAD IN SITU SOLIDIFICATION/STABILIZATION SYSTEMS

S/S techniques can be used alone or combined with other treatment and disposal methods to yi suitable for land disposal or, in other cases, that can be applied to beneficial use. These techi both final and interim remedial measures.

Applicability: The target contaminant group for in situ S/S is inorganics (including radionuclides). The technology against SVOCs and pesticides and no expected effectiveness against VOCs; however, systems desig in treating organics are being developed and tested.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Depth of contaminants may limit some types of application processes.
- Future usage of the site may "weather" the materials and affect ability to ma contaminants.
- Some processes result in a significant increase in volume (up to double the original volu
- Certain wastes are incompatible with variations of this process. Treatability studies are
- Reagent delivery and effective mixing are more difficult than for ex situ applications.
- Like all in situ treatments, confirmatory sampling can be more difficult than for ex situ

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requ ire and Sludge). Data needs include particle size, Atterberg limits, moisture content, metal concer organic content, density, permeability, unconfined compressive strength, leachability, pH, and

Performance Data: S/S technologies are well demonstrated, can be applied to the most common site and waste typ materials handling equipment, and are available competitively from a number of vendors. Mo are also widely available and relatively inexpensive industrial commodities.

In situ S/S processes have demonstrated the capability to reduce the mobility of contaminate 95%.The effects, over the long term, of weathe ring (e.g., freeze-thaw cycles, acid precipita groundwater infiltration, and physical disturbance associated with uncontrolled future land us the integrity of the stabilized mass and contaminant mobility in ways that cannot be predicted

Cost: Costs for cement-based stabilization techniques vary widely according to materials or reagen project size, and chemical nature of contaminants (e.g., types and concentr ation levels for sh

in situ soil mixing/auger techniques average $50 to $80 per cubic meter ($40 to $60 per cul applications and $190 to $330 per cubic meter ($150 to $250 per cubic yard) for the deeper ap

The shallow soil mixing technique processes 36 to 72 metric tons (40 to 80 tons) per hour on a mixing technique averages 18 to 45 metric tons (20 to 50 tons) per hour.

The major factor driving the selection process beyond basic waste compatibility is the availal S/S processes require that potentially large volumes of bulk reagents and additives be trar Transportation costs can dominate project economics and can qu ickly become uneconomica regional material sources are unavailable.

References:

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EPA, 1989. *Hazcon — Solidification*, EPA RREL, series includes Technology Evaluation, Vo PB89-158810; Technology Evaluation, Vol. II, EPA/540/5-89/001b, PB89-158828; EPA/540/A5-89/001; and Technology Demonstration Summary, EPA/540/S5-89/001.

EPA, 1989. *IWT/GeoCon In-Situ Stabilization*, EPA RREL, series includes Technol EPA/540/5-89/004a; Technology Evaluation, Vol. II, EPA/540/5-89/004b, PB89-194179; Te III, EPA/540/5-89/004c, PB90-269069; Technology Evaluation, Vol. IV, EPA/540/5- Applications Analysis, EPA/540/A5-89/004; Technology Demonstration Summary, EPA/54 Demonstration Summary — Update Report, EPA/540/S5-89/004a; and Demonstration Bullet

EPA, 1989. *SITE Program Demonstration Test International Waste Technologies In Situ S Hialeah, Florida*, Technology Evaluation Report, EPA RREL, Cincinnati, OH, EPA/540/5-8

EPA, 1989. *Soliditech, Inc. — Solidification*, EPA RREL, series includes Technology Evalu 89/005a; Technology Evaluation, Vol. II, EPA/540/5-89/005b, PB90-191768; Application 89/005; Technology Demonstration Summary, EPA/540/S5-89/005; and Demonstration 89/005.

EPA, 1989. *Stabilization/Solidification of CERCLA and RCRA Wastes: Physical Procedures, Technology Screening, and Field Activities*,EPA, CERL, Cincinnati, OH, EPA/

EPA, 1990. *International Waste Technologies/Geo-Con In Situ Stabilization/Solidificati* EPA, ORD, Washington, DC, EPA/540/A5-89/004.

EPA, 1993. *Solidification/Stabilization and Its Application to Waste Materials*, Technical R ORD, Washington, DC, EPA/530/R-93/012.

EPA, 1993. *Solidification/Stabilization of Organics and Inorganics*, Engineering Bulletin OH, EPA/540/S-92/015.

Wiles, C.C., 1991. *Treatment of Hazardous Waste with Solidification/Stabilization*, EPA Re

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Hialeah, FL	Jeff Newton International Waste Technologies 150 North Main Street, Suite 910 Wichita, KS 67202 (316) 269-2660 Geo-Con Dave Miller (817) 383-1400	Deep soil mixing using drive auger to inject additive slurry and water into in-place soil.	NA	NA	$111-$194/ton

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Mary K. Stinson	EPA RREL	(908) 321-6683 Fax: (908) 321-6640	2890 Woodbridge Avenue (MS-104) Edison, NJ 08837-3679
Patricia M. Erikson	EPA RREL	(513) 569-7884 Fax: (513) 569-7676	26 West M.L. King Drive Cincinnati, OH 45268
Edward R. Bates	EPA RREL	(513) 569-7774 Fax: (513) 569-7676	26 West M.L. King Drive Cincinnati, OH 45268
John Cullinane	USAE-WES	(601) 636-3111	ATTN: LEWES-EE-S 3909 Halls Ferry Road Vicksburg, MS 39180-6199
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.8 THERMALLY ENHANCED SOIL VAPOR EXTRACTION

Description: Thermally enhanced SVE is a full-scale technology that uses steam/hot -air injection or electri to increase the mobility of semi- volatiles and facilitate extraction. The process is otherwise i (Treatment Technology Profile 4.6).

4-8 TYPICAL THERMALLY ENHANCED SVE SYSTEM

Applicability: The system is designed to treat SVOCs but will consequently treat VOCs. T hermally enhanced S effective in treating some pesticides and fuels, depending on the temperatures achieved by the syste this process, subsurface conditions are excellent for biodegradation of residual contam inants.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- Debris or other large objects buried in the media can cause operating difficulties.
- Performance in extracting certain contaminants varies depending upon the maximum the process selected.
- The soil structure at the site may be modified depending upon the process selected.
- Soil that is tight or has high moisture content has a reduced permeability to air, hi thermally enhanced SVE and requiring more energy input to increase vacuum and tempe
- Soil with highly variable permeabilities may result in uneven delivery of gas flow to the
- Soil that has a high organic content has a high sorption capacity of VOCs, which re rates.
- Air emissions may need to be regulated to eliminate possible harm to the public an treatment and permitting will increase project costs.
- Residual liquids and spent activated carbon may require further treatment.
- Thermally enhanced SVE is not effective in the saturated zone; however, lowering the media to SVE (this may address concerns regarding LNAPLs).

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requiren and Sludge). Data requirements include the depth and areal extent of contamination, tl contaminants, depth to water table, and soil type and properties (e.g., structure, texture, pe content).

Performance Data:

The thermally enhanced SVE processes are notably different and should be investigated indiv information. Because thermally enhanced SVE is an in situ remedy and all contaminants ar operation, the possibility of contaminant release is greatly reduced.

As with SVE, remediation projects using thermally enhanced SVE systems are hi ghly depenc and chemical properties of the contaminated media. The typical site consisting of 18,200 met contaminated media would require approximately 9 months.

DOE has developed and tested several th ermally enhanced SVE processes. Dynamic undergr steam injection and direct electric heating. Six phase soil heating is a pilot-scale technology electric phases through electrodes placed in a circle arou nd a soil vent. Thermally enhanced combines conventional SVE with both powerline frequency and radiofrequency soil heating.

Cost:

Available data indicate the overall cost for thermally enhanced SVE systems is approximate meter ($25 to $100 per cubic yard).

References:

Dev, H., G.C. Sresty, J. Enk, N. Mshaiel, and M. Love, 1989. *Radiofrequency Enhanced Contaminated with Halogenated Hydrocarbons,*EPA RREL, ORD, Cincinnati, OH, EPA Re

DOE, 2 October 1992. *RCRA Research, Development and Demonstration Permit Ap Enhanced Vapor Extraction System,* Sandia National Laboratories, Environmental Department, Albuquerque, NM.

DOE, 26 February 1993. *Technology Name: Thermal Enhanced Vapor Extraction Systen* Profile (Rev. 2) for ProTech, DOE ProTech Database, TTP Reference No.: AL -221121.

EPA, 1990. *Toxic Treatments (USA) — In-Situ Steam/Hot Air Stripping,* EPA RREL, se Analysis, EPA/540/A5-90/008, and Demonstration Bulletin, EPA/540/M5-90/003.

Pedersen, T.A., and J.T. Curtis, 1991. *Soil Vapor Extraction Technology Reference* Cambridge, MA, for EPA RREL, ORD, Cincinnati, OH, EPA Report EPA/540/2-91/003.

WESTON, IIT Research Institute, November 1992. *Final Rocky Mountain Arsenal I*

Heating/Vapor Extraction Pilot Test Report, Vol. I, U.S. Army Report 5300-01-12-AAFP.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Annex Terminal San Pedro, CA	Paul dePercin EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7797	In situ steam and air stripping of soil via hollow-stem, rotating-blade drills.	NA	85% VOC and 55% SVOC removal	$330 to $415/m^3 ($252 to $317/yd^3)
Lockheed Aeronautical Systems Burbank, CA	Norma Lewis EPA 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7665 (513) 569-7684	Integrated groundwater stripping and soil system.	Groundwater: TCE 2.2 ppm PCE 11 ppm Soil gas: Total VOC 6,000 ppm	98-99.9% VOC removal	$4.3M and $630,000 annual O&M for 1,000 gpm system
DOE Sandia National Lab. Albuquerque, NM	James M. Phelan Sandia National Laboratories P.O. Box 5800 Albuquerque, NM 87185 (505) 845-9892	Integrated resistive (powerline) and radio frequency (microwave) heating to remedy organic, fire training, and chemical production waste landfill.	NA	NA	$16-$33/ metric ton ($15-30/ton), varies by soil moisture
Volkfield, WI	Paul Carpenter AL/EQW Tyndall AFB, FL (904) 283-6187	In situ IITRI design.	NA	99% VOC, 83-99% SVOC removal	$45/ton in shallow sand
Kelly AFB, TX	Paul Carpenter AL/EQW Tyndall AFB, FL (904) 283-6187 FAX: (904) 283-6286 DSN: 523-6187 DSN FAX: (904) 523-6286	Two pilot-scale demos of RF heating: IITRI and KAI designs.	NA	>90% VOC and SVOC removal	<$100/ton in shallow clay

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Skip Chamberlain	DOE Program Manager	(301) 903-7248	EM-551, Trevion II DOE Washington, DC 20585
Gordon M. Evans	EPA RREL	(513) 569-7684	26 West M.L. King Drive

		Fax: (513) 569-7620	Cincinnati, OH 45268
Darrell Bandy	DOE Albuquerque Operations	(505) 845-6100	P.O. Box 5400 Albuquerque, NM 87115-5400
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.9 IN SITU VITRIFICATION

Description: In situ vitrification (ISV) uses an electric current to melt soil or other earthen materials at extr (1,600 to 2,000 ?C or 2,900 to 3,650 ?F) and thereby immobilize most inorganics and destr pyrolysis. Inorganic pollutants are incorporated within the vitrified glass and crystalline organic pyrolysis combustion products are captured in a hood, which draws the contaminants system that removes particulates and other pollutants from the gas.

4-9 TYPICAL IN SITU VITRIFICATION SYSTEM

High temperatures are achieved using a square array of four graphite electrodes. To initiat conducting material (graphite) is placed on the surface of the soil so that current can flow in th temperature of water (dry soil is not conductive after the conduction path in soil pore water is b

point of the soil. The joule heating of t he starter path achieves temperatures high enough t dependent on the soil's alkali metal oxide content), at which point the soil becomes conductive grows downward and outward. New designs incorporate a movin g electrode mechanism to a depth. A vacuum pressurized hood is placed over the vitrification zone to contain and pr emanating from the soil during vitrification. The vitrification product is a chemically stable, crystalline material similar to obsidian or basalt rock. The process destroys and/or rer Radionuclides and heavy metals are retained within the molten soil.

The ISV process was invented by Battelle , Pacific Northwest Laboratory for DOE in 1980. DOE, is licensed to Battelle, and is sublicensed to Geosafe Corporation for worldwide rights issued 15 March 1983).

Applicability: The ISV process can destro y or remove organics and immobilize most inorganics in contaminatec earthen materials. The process has been tested on a broad range of VOCs and SVOCs, other organi PCBs, and on most priority pollutant metal s and radionuclides.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Rubble exceeding 20% by weight.
- Heating the soil may cause subsurface migration of contaminants into clean areas.
- Combustible organics in the soil or sludge exceeding 5 to 10 weight percent (wt%), d value.
- The solidified material may hinder future site use.
- Processing of contamination below the water table may require some means to limit recl

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requiren and Sludge). A minimum alkali content in soil (sodium and potassium oxides) of 1.4 wt% is The composition of most soils is well within the range of processability.

Performance Data:

There have been few, if any, commercial applications of ISV. The ISV process has bee demonstration purposes at the pilot scale and at full sca le at the following sites: (1) Geosafe C DOE's Hanford Nuclear Reservation, (3) DOE's Oak Ridge National Laboratory, and (4 Engineering Laboratory. More than 170 tests at various scales have been performed on a br in soils and sludges. A demonstration will take place at the Parsons/ETM site in Grand Lec process is currently operating.

Process depths up to 6 meters (19 ft) have been achieved in re latively homogeneous soils. limited under certain heterogeneous conditions.

Cost:

Average costs for treatability tests (all types) are $25K plus analytical fees; for PCBs and plus analytical. Remedial design varies with the design firm. Equipment mobilization and $200K to $300K combined. Vitrification operation cost varies with electricity costs, quantit process.

References:

DOE, 1992. *In Situ Vitrification*, Technology Transfer Bulletin, prepared by Battelle's Pacifi for DOE, Richland, WA.

DOE, January 1992. "ISV Planning and Coordination," *FY92 Technical Task Plan and Tec* TTP Reference No. RL-8568-PT.

DOE, July 1992. "116-B-6A Crib ISV Demonstration Project," *FY92 Technical Task P Description*, TTP Reference No. RL-8160-PT.

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Kuhn, W.L., May 1992. *Steady State Analysis of the Fate of Volatile Contaminants Du* Battelle, Pacific Northwest Laboratory, Richland, WA, prepared for DOE; PNL-8059, US-60

Luey, J.S., S. Koegler, W.L. Kuhn, P.S. Lowerey, and R.G. Winkelman, September 1992. *Mixed-Waste Contaminated Soil Site: The 116-B-6A Crib at Hanford,"* CERCLA Treatabi Pacific Northwest Laboratory, Richland, WA, prepared for DOE, Report PNL-8281, UC-602

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Radioactive Pilot-Scale Test of In Situ Vitrification for the Stabilization of Contaminated Sc
Marietta Energy Systems, Publication No. 3962, prepared for DOE, Oak Ridge National Lab
Report ORNL/TM-12201.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Parson's Chemical Site Grand Ledge, MI	Leonard Zintak, Jr. (517) 627-1311 Fax: (517) 627-1594	Four graphite electrodes and glass frit inserted into soil. Hood and off-gas treatment system placed over soil.	Low levels of pesticides and Hg	Leachable Hg, TCLP, pesticide, non-detect	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Jef Walker	DOE Program Manager	(301) 903-7966	EM-541, Trevion II DOE Washington, DC 20585
Teri Richardson	EPA RREL	(513) 569-7949 Fax: (513) 569-7620	26 West M.L. King Drive Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.10 COMPOSTING

Description: Composting is a controlled biological process by which biodegradable hazardous mat microorganisms to innocuous, stabilized byproducts, typically at elevated temperatures in t (120 to 130 ?F). The increased temperatures result from heat produced by microorganisms the organic material in the waste. In most cases, this is achieved by the use of indigenous m excavated and mixed with bulking agents and organic amendments, such as wood chips, anim to enhance the porosity of the mixture to be decomposed. Maximum degradation efficiency is moisture content, pH, oxygenation, temperature, and the carbon -to-nitrogen ratio.

4-10 TYPICAL WINDROW COMPOSTING PROCESS

There are three process designs used in composting: aerated static pile composting (compost

aerated with blowers or vacuum pumps), mechanically agitated in-vessel composting (comp vessel where it is mixed and aerated), and windrow composting (compost is placed in long p and periodically mixed with mobile equipment). Windrow composting has the potential to b composting alternative. If VOC or SVOC contaminants are present in soils, off-gas control is

Applicability: The composting process may be applied to soils and lagoon sediments contaminated with biodegrada Research and development and pilot efforts have demonstrated that aerobic, thermophilic composti concentration of explosives (TNT, RDX, and HMX) and associated toxicity to acceptable le equipment used for composting are commercially available.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- Substantial space is required for composting.
- Excavation of contaminated soils is required and may cause the uncontrolled release of
- Composting results in a volumetric increase in material because of the addition of amen
- Heavy metals are not treated by this method and can be toxic to the microorganisms.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requiren and Sludge). Specific data required to evaluate the compost process include contaminant c requirements, availability and cost of amendments required for compost mixture, space ava type, nutrients, biodegradation capacity, and moisture-holding capacity.

Performance Data: Windrow composting has been demonstrated as an effective technology for treatment of exp During a field demonstration conducted by USAEC and the Umatilla Depot Activity (UMDA as high as 99.7% in 40 days of operation, with the majority of removal occurring in the fi Maximum removal efficiencies for RDX and HMX were 99.8% and 96.8%, respectively equipment requirements combined with these performance results make windrow compo technically attractive.

Cost: Costs will vary with the amount of soil to be treated, the soil fraction in the compost, availat type of contaminant, and the type of process design employed. Estimated costs for full-scal

explosives-contaminated soils are approximately $190 per cubic yard for soil volumes of a
Estimated costs for static pile composting and mechanically agitated in vessel composting are l
be an economic alternative to thermal treatment, howev er, when cleanup criteria and reg
suitable.

References:

Ayorinde, O. and M. Reynolds, December 1989. "Low Temperature Effects on Syste
Explosives-Contaminated Soils," Part I, *Literature Reviews*, USACRREL.

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0079, Report No. CETHA-TS-CR-93043.

Williams, R.T., P.S. Ziegenfuss, and P.J. Marks, September 1988. *Field Demonstration - C*
Contaminated Sediments at the Louisiana Army Ammunition Plant, USATHAMA Report AM

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Contaminated Sediments at the Badger Army Ammunition Plant (BAAP), USATHAMA
89061.

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USATHAMA Report CETHA-TS-CR-91053.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
UMDA Hermiston, OR	USAEC ETD APG, MD 21010 (410) 671-2054	Successful large-scale pilot demonstration of windrow composting	1,563 ppm TNT 953 ppm RDX 156 ppm HMX	4 ppm TNT 2 ppm RDX 5 ppm HMX	$210/metric ton ($190/ton) for large-scale (20,000 tons) cleanup
LAAP Shreveport, LA	USAEC ETD APG, MD 21010 (410) 671-2054	Successful pilot-scale demonstration of mechanical in-vessel composting	5,200 ppm TNT 500 ppm RDX	20 ppm TNT 20 ppm RDX	NA
Cliff/Dow Disposal Site Marquette, MI	EPA Region V Ken Glatz (312) 886-1434	Aerobic/indigenous organism treatment of 7,000 m^3; basically unsuc-cessful study	PAHs, As, Cu, Pb, Hg	Destroyed only the lower mole-cular weight PAHs; did not reach safety level desired	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
John Cullinane or Judith Pennington	USAE-WES	(601) 636-3111	3909 Halls Ferry Road Vicksburg, MS 39180-6199
Carl Potter	EPA RREL	(513) 569-7231	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.11 CONTROLLED SOLID PHASE BIOLOGICAL TREATMENT

Description: Controlled solid phase biological treatment is a full-scale technology in which excavated s amendments and placed on a treatment area that includes leachat e collection systems and Controlled solid phase processes include prepared treatment beds, biotreatment cells, and so nutrients, oxygen, and pH can be controlled to enhance biodegradation.

4-11 TYPICAL CONTROLLED TREATMENT UNIT FOR SOLID-PHASE BIOREMEDIATION

A variety of techniques are used to stimulate the bioremediation. If required, the treatment contained with an impermeable liner to minimize the risk of contaminants leaching into an un prepared bed bioremediation techniques involve the continuous spray application of a nutrient collection and recycle of the drainage from the soil p ile. The drainage itself may be treat recycling. Vendors have developed proprietary nutrient and additive formulations and metho

formulation into the soil to stimulate biodegradation. The formulations are usually r conditions.

Soil piles and biotreatment cells commonly have an air distribution system buried under the sc soil either by vacuum or by positive pressure. The soil piles in this case can be up to 20 fee covered with plastic to control runoff, evaporation, and volatilization and to promote solar hea in the soil that will volatilize into the air stream, the air leaving the soil may be treated to rem before they are discharged to the atmosphere.

Applicability: Controlled solid-phase biological treatment is most effective in treating nonhalogenated VOCs Halogenated VOCs, SVOCs, and pesticides also can be treated, but the process may be less effecti only to some compounds within these contaminant groups.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- A large amount of space is required.
- Excavation of contaminated soils is required.
- Treatability testing should be conducted to determine the biodegradability of contai oxygenation and nutrient loading rates.
- Solid phase processes have questiona ble effectiveness for halogenated compounds and r in degrading transformation products of explosives.
- Similar batch sizes require more time to complete cleanup than slurry phase processes.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requiren and Sludge). The first steps in preparing a sound design for biotreatment of contaminated soil

- Site characterization.
- Soil sampling and characterization.
- Contaminant characterization.
- Laboratory and/or field treatability studies.
- Pilot testing and/or field demonstrations.

Site, soil, and contaminant characterizations will be used to:

- Identify and quantify contaminants.
- Determine requirements for organic and inorganic amendments.
- Identify the presence of organic compounds that may be volatilized during composting.
- Identify potential safety issues.
- Determine requirements for excavation, staging, and movement of contaminated soil.
- Determine availability and location of utilities (electricity and water).

Laboratory or field treatability studies are needed to identify:

- Amendment mixtures that best promote microbial activity.
- Potential toxic degrada tion byproducts.
- Percent reduction and lower concentration limit of contaminant achievable.
- The potential degradation rate.

Performance Data: Controlled solid phase biological treatment has been demonstrated for fuel -contamina information is contained in the following site information table.

Cost: Costs are dependent on the contaminant, procedure to be used, need for additional pre - and for air emission control equipment. Controlled solid phas e processes are relatively simple a for operation and maintenance. Typical costs with a prepared bed and liner are $130 to $260 $200 per cubic yard).

References: Hartz, A.A. and R.B. Beach, 1992. "Cleanup of Creosote-Contaminated Sludge Using

Proceedings of the HMC/Superfund '92, HMCRI, Greenbelt, MD.

Norris, et al., 1994. *Handbook of Bioremediation*, EPA-RSKERL, Lewis Publishers, CR Boulevard, Boca Raton, FL 33431.

Pope, D.F. and J.E. Matthews, 1993. *Bioremediation Using the Land Treatment Concept*, 93/164.

Sims, J.L., et al., 1989. *Bioremediation of Contaminated Surface Soils*, EPA, RSKERL EPA/600/9-89/073.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Marine Corps Mountain Warfare Training Center Bridgeport, CA	Bill Major NFESC, Code 411 Port Hueneme, CA 93043 (805) 982-1808	Pilot study at fuel-leaking UST site — aerated soil pile on lined bed	TPH 1,200 ppm	120 ppm after 2 months	$88/metric ton ($80/ton)
Marine Corps Air Ground Combat Center Twenty-Nine Palms, CA	R.L. Biggers NFESC, Code 414 Port Hueneme, CA 93043 (805) 982-2640	Fuel from UST and spills — heap pile research project	702 ppm average TPH	234 ppm average	$36/m^3 ($27/yd^3)
Mobil Terminal Buffalo, NY	Robert Leary or Sal Calandra (716) 851-7220	CERCLA LEAD - full-scale aerated biocell remediation since July 1991 of 11,500 m^3; non-native organisms added	gas, diesel, lead	NYSDEC guidance based on TCLP	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Teri Richardson	EPA RREL	(513) 569-7949 Fax: (513) 569-7620	26 West M.L. King Drive Cincinnati, OH 45268
John Cullinane	USAE-WES	(601) 636-3111	Attn: CEWES-EE-S 3909 Halls Ferry Road Vicksburg, MS 39180-6199
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.12 LANDFARMING

Description: Landfarming is a full-scale bioremediation technology in which contaminated soils, sediments, or sludges are applied onto the soil surface and periodically turned over or tilled into the soil to aerate the waste. Although landfarming is usually performed in place, landfarming systems are increasingly incorporating liners and other methods to control leaching of contaminants, which requires excavation and placement of contaminated soils.

4-12 TYPICAL LANDFARMING TREATMENT UNIT

Soil conditions are often controlled to optimize the rate of contaminant degradation. Conditions normally controlled include:

- Moisture content (usually by irrigation or spraying).
- Oxygen level (by mixing the soil using tilling or aerating).
- Nutrients, primarily nitrogen and phosphorus (by fertilizing).
- pH (increased slightly by adding lime).
- Soil bulking (by adding soil amendments and by mixing using tilling, etc.).

Applicability: Soil bioremediation has been proven most successful in treating petroleum hydrocarbons. Because lighter, more volatile hydrocarbons such as gasoline are treated very successfully by processes that use their volatility [i.e., soil vapor (vacuum) extraction and bioventing], the use of aboveground bioremediation is

usually limited to heavier hydrocarbons. As a rule of thumb, the higher the molecular weight (and the more rings with a PAH), the slower the degradation rate. Also, the more chlorinated or nitrated the compound, the more difficult it is to degrade. (Note: Many mixed products and wastes include some volatile components that transfer to the atmosphere before they can be degraded.)

Contaminants that have been successfully treated include diesel fuel, No. 2 and No. 6 fuel oils, JP-5, oily sludge, wood-preserving wastes (PCP and creosote), coke wastes, and certain pesticides.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- A large amount of space is required.
- If excavation of contaminated soils is required, materials handling and additional costs will be involved.
- Conditions advantageous for biological degradation of contaminants are largely uncontrolled, which increases the length of time to complete remediation, particularly for recalcitrant compounds.
- Reduction of VOC contaminant concentrations may be caused more by volatilization than biodegradation.
- Inorganic contaminants will not be biodegraded.
- Volatile contaminants, such as solvents, must be pretreated because they would evaporate into the atmosphere, causing air pollution.
- Particulate matter is also a concern because it may cause a dust-generation problem.
- Presence of metal ions may be toxic to the microbes and possibly leach from the contaminated soil into the ground.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). The following contaminant considerations should be addressed prior to implementation: types and concentrations of contaminants, depth profile and distribution of contaminants, presence of toxic contaminants, presence of VOCs, and presence of inorganic contaminants (e.g., metals).

The following site and soil considerations should be addressed prior to implementation: surface geological features (e.g., topography and vegetative cover), subsurface geological and hydrogeological features, temperature, precipitation, wind velocity and direction, water availability, soil type and texture, soil moisture content, soil organic matter content, cation exchange

capacity, water-holding capacity, nutrient content, pH, atmospheric temperature, permeability, and microorganisms (degradative populations present at site).

Performance Data: Numerous full-scale operations have been used, particularly for sludges produced by the petroleum industry. As with other biological treatments, under proper conditions, landfarming can transform contaminants into nonhazardous substances. Removal efficiencies, however, are a function of contaminant type and concentrations, soil type, temperature, moisture, waste loading rates, application frequency, aeration, volatilization, and other factors.

Cost: Ranges of costs likely to be encountered are:

- Costs prior to treatment (assumed to be independent of volume to be treated): $25,000 to $50,000 for laboratory studies; $100,000 to $500,000 for pilot tests or field demonstrations.

- Cost of landfarming (in situ treatment requiring no excavation of soil): $30 to $70 per cubic meter ($25 to $50 per cubic yard).

- Cost of prepared bed (ex situ treatment and placement of soil on a prepared liner): $135 to $270 per cubic meter ($100 to $200 per cubic yard).

References:

EPA, 1990. *Bioremediation in the Field*, EPA/540/2-90-004.

Norris, et al., 1994. *Handbook of Bioremediation*, EPA, RSKERL, Lewis Publishers, CRC Press, 200 Corporate Boulevard, Boca Raton, FL 33431.

Pope, D.F. and J.E. Matthews, 1993. *Bioremediation Using the Land Treatment Concept*, EPA Report EPA/600/R-93/164.

Sims, J.L., et al., 1989. *Bioremediation of Contaminated Surface Soils*, EPA, RSKERL, EPA Report EPA/600/9-89/073.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Petroleum Products Terminal	Al Leuscher Remediation Technologies, Inc. Concord, MA	Soils segregated by contamination type treated for 3 years (seasonal operation)	TPH 1,000 ppm	100 ppm	NA
Fuel Oil Spill	Joe Matthewson Foster Wheeler Santa Fe Springs, CA	Heavy clays required addition of soil amendments— 120 treatment days	TPH 6,000 ppm	100 ppm	NA
Creosote	John Matthews EPA RSKERL P.O. Box 1198 Ada, OK 74821 (405) 436-8600	NPL — Ongoing seasonal operation	Pyrene 135 ppm PCP 132 ppm	Less than 7.3 ppm 87 ppm	NA
Pesticide Storage Facility	NA	12-inch clay liner with drainage employed— 5 months' treatment	Pesticide 86 ppm	5 ppm	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Richard Scholze	USACE-CERL	(217) 373-6743 (217) 352-6511 (800) USA-CERL	P.O. Box 9005 Champaign, IL 61826-9005
Ron Hoeppel	NFESC	(805) 982-1655	Code 411 Port Hueneme, CA 93043
Mark Zappi	USAE-WES	(601) 634-2856	Vicksburg, MS 39180
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.13 SLURRY PHASE BIOLOGICAL TREATMENT

Description: Slurry phase biological treatment involves the controlled treatment of excavated soil in a bioreactor. The excavated soil is first processed to physically separate stones and rubble. The soil is then mixed with water to a predetermined concentration dependent upon the concentra tion of the contaminants, the rate of biodegradation, and the physical nature of the soils. Some processes pre-wash the soil to concentrate the contaminants. Clean sand may then be discharged, leaving only contaminated fines and washwater to biotreat. Typically, the slurry contains from 10 to 40% solids by weight.

4-13 TYPICAL BIOREACTOR PROCESS

The soil is maintained in suspension in a reactor vessel and mixed with nutrients and oxygen. If necessary, an acid or alkali may be added to control pH. Microorganisms also may be added if a suitable population is not present. When biodegradation is complete, the soil slurry is dewatered. Dewatering devices that may be used include clarifiers, pressure filters, vacuum filters, sand drying beds, or centrifuges.

Applicability: Bioremediation techniques have been successfully used to remediate soils, sludges, and groundwater contaminated by explosives, petroleum hydrocarbons, petrochemicals, solvents, pesticides, wood preservatives, and other organic chemicals. Bioremediation is not applicable for removal of inorganic contaminants. Bioreactors are favored over in situ biological techniques for heterogenous soils, low permeability soils, areas where underlying groundwater would be difficult to capture, or when faster treatment times are required.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Excavation of contaminated soils is required.
- Sizing of materials prior to putting them into the reactor can be difficult and expensive. Nonhomogeneous soils can create serious materials handling problems.
- Dewatering soil fines after treatment can be expensive.
- An acceptable method for disposing of nonrecycled wastewaters is required.

Performance Data: Mobile treatment units that are quickly moved into and out of the site are available. Residence time in the bioslurry reactors will vary depending on the nature of the contaminants, their concentrations, and the desired level of removal. Residence time is typically 5 days for PCP-contaminated soil, 13 days for a pesticide-contaminated soil, and 60 days for refinery sludge.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Although a specific organic substance might have been shown to be amenable to biodegradation in the laboratory or at other remediation sites, whether it degrades in any specific soil/site condition is dependent on many factors. To determine whether bioremediation is an appropriate and effective remedial treatment for the contaminated soil at a particular site, it is necessary to characterize the contamination, soil, and site, and to evaluate the biodegradation potential of the contaminants.

Important contaminant characteristics that need to be identified in a bioremediation feasibility investigation are their solubility and soil sorption coefficient; their volatility (e.g., vapor pressure); their chemical reactivity (e.g., tendency toward nonbiological reactions such as hydrolysis, oxidation, and polymerization); and their biodegradability.

In a Navy bench-scale evaluation, the system has demonstrated 99.5% and 100% remediation of TNT and RDX, respectively.

Cost: Treatment costs using slurry reactors range from $130 to $200 per cubic meter ($100 to $150 per cubic yard). Costs ranging from $160 to $210 per cubic meter ($125 to $160 per cubic yard) are incurred when the slurry-bioreactor off-gas has to be further treated because of the presence of volatile compounds.

References:

EPA, 1990. *Slurry Biodegradation*, Engineering Bulletin, EPA/540/2-90/016.

EPA, 1991. *Pilot-Scale Demonstration of Slurry-Phase Biological Reactor for Creosote-Contaminated Wastewater*, EPA RREL, series includes Technology Demonstration Summary, EPA/540/S5-91/009; Technology Evaluation Vol. I, EPA/540/5-91/009, PB93-205532; Applications Analysis, EPA/540/A5 91/009; and Demonstration Bulletin, EPA/540/M5-91/009.

EPA, 1992. *Bioremediation Case Studies, Abstracts*, EPA, Washington, DC, EPA/600/R-92/004.

EPA, 1992. *Biotrol Soil Washing System for Treatment of a Wood Preserving Site*, Applications Analysis Report, EPA, ORD, Washington, DC, EPA/540/A5-91/003.

EPA, Undated. *International Technology Corporation—Slurry Biodegradation*, EPA RREL.

Montamagno, C.D., 1990. *Feasibility of Biodegrading TNT-Contaminated Soils in a Slurry Reactor - Final Technical Report*, USATHAMA Report CETHA-TE-CR-90062.

Zappi, M.E., D. Gunnison, C.L. Teeter, and N.R. Francigues, 1991. *Development of a Laboratory Method for Evaluation of Bioslurry Treatment Systems*, Presented at the 1991 Superfund Conference, Washington, DC.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
NWS Seal Beach, CA	Steve MacDonald NWS Seal Beach Code 0923 Seal Beach, CA 90740 (310) 594-7273	Pilot scale- BTEX-contaminated soil and groundwater treated simultaneously.	NA	Treated to drinking water standards	NA
EPA BDAT	Ronald Lewis RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7856 Fax: (513) 569-7620	Pilot scale- creosote and PAH contamination.	NA	96% PAH removal in 2 weeks	NA
Joliet AAP Joliet, IL	John Manning or Carlo Montemagno Argonne National Lab 9700 South Cass Ave. Argonne, IL 604394815	Pilot scale- explosive contamination.	TNT 1,300 ppm	10 mg/kg in 15 days	$65 to $262/m^3 ($50-$200/yd^3)

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Carmen Lebron	NFESC	(805) 982-1615	Code 411 Port Hueneme, CA 93043
Mark E. Zappi	USA WES	(601) 634-2856	3903 Halls Ferry Road Vicksburg, MS 39180-6199
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401
Mary K. Stinson	EPA RREL	(908) 321-6683	2890 Woodbridge Ave. MS-104 Edison, NJ 08837-3679

4.14 CHEMICAL REDUCTION/OXIDATION

Description: Reduction/oxidation (Redox) reactions chemically convert hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. Redox reactions involve the transfer of electrons from one compound to another. Specifically, one reactant is oxidized (loses electrons) and one is reduced (gains electrons). The oxidizing agents most commonly used for treatment of hazardous contaminants are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide. Chemical redox is a full-scale, well-established technology used for disinfection of drinking water and wastewater, and it is a common treatment for cyanide wastes. Enhanced systems are now being used more frequently to treat contaminants in soils.

4-14 TYPICAL CHEMICAL REDUCTION/OXIDATION PROCESS

Applicability: The target contaminant group for chemical redox is inorganics. The technology can be used but may be less effective against nonhalogenated VOCs and SVOCs, fuel hydrocarbons, and pesticides.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Incomplete oxidation or formation of intermediate contaminants may occur depending upon the contaminants and oxidizing agents used.
- The process is not cost-effective for high contaminant concentrations

because of the large amounts of oxidizing agent required.

- Oil and grease in the media should be minimized to optimize process efficiency.

Data Needs: A detailed discussion of these data elements is pro vided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Treatability tests should be conducted to identify parameters such as water, alkaline metals, and humus content in the soils; the presence of multiple phases; and total organic halides that could affect processing time and cost.

Performance Data: Chemical redox is a full-scale, well-established technology used for disinfection of drinking water and wastewater, and it is a common treatment for cyanide and chromium wastes. Enhanced systems are now being used more frequently to treat hazardous wastes in soils.

Cost: Estimated costs range from $190 to $660 per cubic meter ($150 to $500 per cubic yard).

References:

EPA, Undated. *Lawrence Livermore National Laboratory Superfund Site*, Project Summary, EPA/540/SR-93/516.

EPA, 1991. *Chemical Oxidation Treatment*, Engineering Bulletin, EPA, OERR and ORD, Washington, DC, EPA/530/2-91/025.

Mayer, G., W. Bellamy, N. Ziemba, and L.A. Otis, 15-17 May 1990. "Conceptual Cost Evaluation of Volatile Organic Compound Treatment by Advanced Ozone Oxidation," *Second Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International*, Philadelphia, PA, EPA, Washington, DC, EPA Report EPA/2-90/010.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Excalibur Technology	Norma Lewis EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7665	Bench scale— Soil washing and catalytic ozone oxidation Site demo scheduled for Coleman Evans, Florida	20,000 ppm	NA	$92 to $170/m^3 ($70-$130/yd^3)

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Naomi Barkley	EPA RREL	(513) 569-7854 Fax: (513) 569-7620	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.15 DEHALOGENATION (BASE-CATALYZED DECOMPOSITION)

Description: The dehalogenation [base-catalyzed decomposition (BCD)] process was developed by EPA's Risk Reduction Engineering Laboratory (RREL), in cooperation with the National Facilities Engineering Services Center (NFESC) to remediate soils and sediments contaminated with chlorinated organic compounds, especially PCBs, dioxins, and furans. Contaminated soil is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate. The mixture is heated to above 330 ?C (630 ?F) in a rotary reactor to decompose and partially volatilize the contaminants.

4-15 TYPICAL BCD DEHALOGENATION PROCESS

The contaminant is partially decomposed rather than being transferred to another medium. Whereas alkaline polyethylene glycol (APEG) residuals contain chlorine and hydroxyl groups, which make them water-soluble and slightly toxic, the BCD process produces primarily biphenyl and low-boiling point olefins, which are not water-soluble and are much less toxic, and sodium chloride.

Applicability: The target contaminant groups for dehalogenation (BCD) are halogenated SVOCs and pesticides. The technology can be also used to treat halogenated VOCs but will generally be more expensive than other alternative technologies.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- High clay and moisture content will increase treatment costs.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Treatability tests should be conducted to identify parameters such as water, alkaline metals, and humus content in the soils; the presence of multiple phases; and total organic halides that could affect processing time and cost.

Performance Data: NFESC and EPA have been jointly developing the BCD process since 1990. Data from the Koppers Superfund site in North Carolina are inconclusive regarding technology performance because of analytical difficulties. There have been no commercial applications of this technology to date. The BCD process has received approval by EPA's Office of Toxic Substances under the Toxic Substances Control Act for PCB treatment. Complete design information is available from NFESC, formerly NCEL and NEESA. Predeployment testing was completed at Naval Communications Station Stockton in November 1991. The research, development, testing, and evaluation stages were planned for Guam during the first two quarters of FY93. A successful test run with 15 tons of PCB soil was conducted in February 1994.

Cost: The cost for full-scale operation is estimated to be $270 per metric ton ($245 per ton) and does not include excavation, refilling, residue disposal, or analytical costs. Factors such as high clay or moisture content may raise the treatment cost slightly.

References:

EPA, 1991. *BCD: An EPA-Patented Process for Detoxifying Chlorinated Wastes*, EPA, ORD.

NCEL, 1990. *Engineering Evaluation/Cost Analysis for the Removal and Treatment of PCB-Contaminated Soils at Building 3000 Site PWC Guam.*

NEESA and NCEL, August 1991. *Chemical Dehalogenation Treatment: Base-Catalyzed Decomposition Process,* Technical Data Sheet.

NEESA and NCEL, July 1992. *Chemical Dehalogenation Treatment: Base-Catalyzed Decomposition Process,* Technical Data Sheet.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Kopper's Superfund Site, NC	NA	Data inconclusive because of analytical data.	NA	NA	NA
PWC Guam	Jess Lizama	PCB	2,500 ppm PCB average	<10 ppm	NA

NA = Not Available.

Points of Contact

Contact	Government Agency	Phone	Location
Deh Bin Chan, Ph.D.	NFESC	(805) 982-4191 Autovon 551-4191	Code 411 560 Center Drive Port Hueneme, CA 93043
R.L. Biggers	NFESC	(805) 982-2640	Code 414 Port Hueneme, CA 93043
Charles J. Rogers	EPA RREL	(513) 569-7757	26 West M.L. King Drive Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.16 DEHALOGENATION (GLYCOLATE)

Description: Dehalogenation (glycolate) is a full-scale technology in which an alkaline polyethylene glycol (APEG) reagent is used to dehalogenate halogenated aromatic compounds in a batch reactor. Potassium polyethylene glycol (KPEG) is the most common APEG reagent. Contaminated soils and the reagent are mixed and heated in a treatment vessel. In the APEG process, the reaction causes the polyethylene glycol to replace halogen molecules and render the compound nonhazardous or less toxic. For example, the reaction between chlorinated organics and KPEG causes replacement of a chlorine molecule and results in a reduction in toxicity. Dehalogenation (APEG/KPEG) is generally considered a standalone technology; however, it can be used in combination with other technologies. Treatment of the wastewater generated by the process may include chemical oxidation, biodegradation, carbon adsorption, or precipitation.

4-16 TYPICAL DEHALOGENATION (GLYCOLATE) PROCESS

The metal hydroxide that has been most widely used for this reagent preparation is potassium hydroxide (KOH) in conjunction with polyethylene glycol (PEG) (typically, average molecular weight of 400) to form a polymeric alkoxide referred to as KPEG. Sodium hydroxide has also been used in the past, however, 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. 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. 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.

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 here and are not considered APEG processes.

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.

Applicability: The target contaminant groups for glycolate dehalogenation are halogenated SVOCs and pesticides. The technology can be used but may be less effective against selected halogenated VOCs. APEG dehalogenation is one of the few processes available other than incineration that has been successfully field tested in treating PCBs. The technology is amenable to small-scale applications.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- The technology is generally not cost-effective for large waste volumes.
- Media water content above 20% requires excessive reagent volume.
- Concentrations of chlorinated organics greater than 5% require large volumes of reagent.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Treatability tests should be conducted to identify parameters such as water, alkaline metals, and humus content in the soils; the presence of multiple phases; and total organic halides that could affect processing time and cost.

Performance Data: Dehalogenation (glycolate) has been used to successfully treat contaminant concentrations of PCBs from less than 2 ppm to reportedly as high as 45,000 ppm. This technology has received approval from the EPA's Office of Toxic Substances under the Toxic Substances Control Act for PCB treatment.

The APEG process has been selected for cleanup of PCB-contaminated soils at three Superfund sites: Wide Beach in Erie County, New York (September 1985); Re-Solve in Massachusetts (September 1987); and Sol Lynn in Texas (March 1988).

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 PCB treatment 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.

The concentrations of PCBs that have been treated are reported to be as high as 45,000 ppm. Concentrations were reduced to less than 2 ppm per individual PCB congener. PCDDs and 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 .

Cost:

Costs to use APEG treatment are expected to be in a range of $220 to $550 per metric ton ($200 to $500 per ton). 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.

References:

EPA, 1987. *Catalytic Dehydrohalogenation: A Chemical Destruction Method for Halogenated Organics*, Project Summary, EPA/600/52-86/113.

EPA, 1989. *Innovative Technology — Glycolate Dehalogenation*, EPA, OSWER, Washington, DC, Directive 9200 5-254FS.

EPA, 1990. *Chemical Dehalogenation Treatment: APEG Treatment*, Engineering Bulletin, EPA, OERR and ORD, Washington, DC, EPA/540/2-90/015.

EPA, 1990. *Treating Chlorinated Wastes with the KPEG Process*, Project Summary, EPA RREL, Cincinnati, OH, EPA/600/S2-90/026.

EPA, 1992. *A Citizen's Guide to Glycolate Dehalogenation*, EPA, OSWER, Washington, DC, EPA/542/F-92/005.

Taylor, M.L., et al. (PEI Associates), 1989. *Comprehensive Report on the KPEG Process for Treating Chlorinated Wastes*, EPA Contract No. 68-03-3413, EPA RREL, Cincinnati, OH.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Montana Pole Butte, MT	NA	Dioxin, Furans/Oil	<84 ppm	<1 ppb	NA
Wide Beach Erie County, NY	NA	PCBs (Aroclor 1254)/soil	120 ppm	<2 ppm	NA
Economy Products Omaha, NE	NA	TCDD, 2, 4-D, 2, 4, 5-T (liquid)	1.3 ppm 17,800 ppm 2,800 ppm	Non-detect 334 ppm 55 ppm	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Carl Brunner	EPA RREL	FTS 684-7757 (513) 569-7757	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.17 SOIL WASHING

Description: Soil washing is a water-based process for scrubbing soils ex situ to remove 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).
- By concentrating them into a smaller volume of soil through particle size separation, gravity separation, and attrition scrubbing (similar to those techniques used in sand and gravel operations).

Soil washing systems incorporating most of the removal techniques offer the greatest promise for application to soils contaminated with a wide variety of heavy metal, radionuclides, and organic contaminants. Commercialization of the process, however, is not yet extensive.

4-17 TYPICAL SOIL WASHING PROCESS

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, silt, and organic 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 of. Gravity separation is effective for removing high or low specific gravity particles such as heavy metal-containing compounds (lead, radium oxide, etc.). Attrition scrubbing removes adherent contaminant films from coarser particles. The clean, larger fraction can be returned to the site for continued use.

Applicability: The target contaminant groups for soil washing are SVOCs, fuels, and inorganics. The technology can be used on selected VOCs and pesticides. The technology offers the potential for recovery of metals and can clean a wide range of organic and inorganic contaminants from coarse-grained soils.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Fine soil particles (e.g., silt, clays) may require the addition of a polymer to remove them from the washing fluid.
- Complex waste mixtures (e.g., metals with organics) make formulating washing fluid difficult.
- High humic content in soil may require pretreatment.
- The aqueous stream will require treatment.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Particle size distribution (0.24 to 2 mm optimum range); soil type, physical form, handling properties, and moisture content; contaminant type and concentration; texture; organic content; cation exchange capacity; pH and buffering capacity.

Performance Data: At the present time, soil washing is used extensively in Europe but 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.

Soil washing is most commonly used in combination with the following technologies: bioremediation, incineration, and solidification/stabilization. Depending on the process used, the washing agent and soil fines are residuals that require further treatment. When contaminated fines have been separated, coarse-grain soil can usually be returned clean to the site. The time to complete cleanup of the "standard" 18,200-metric-ton (20,000-ton) site using soil washing would be less than 3 months.

Cost: The average cost for use of this technology, including excavation, is approximately $130 to $220 per metric ton ($120 to $200 per ton), depending on the target waste quantity and concentration.

References:

EPA, 1989. *Innovative Technology: Soil Washing,* OSWER Directive 9200.5-250FS.

EPA, 1989. *Soils Washing Technologies for: Comprehensive Environmental Response, Compensation, and Liability Act, Resource Conservation and Recovery Act, Leaking Underground Storage Tanks, Site Remediation.*

EPA, 1990. *Soil Washing Treatment,* Engineering Bulletin, EPA, OERR, Washington, DC, EPA/540/2-90/017. Available from NTIS, Springfield, VA, Order No. PB91-228056.

EPA, 1991. *Biotrol—Soil Washing System,* EPA RREL, series includes Technology Evaluation Vol. I, EPA/540/5-91/003a, PB92-115310; Technology Evaluation Vol. II, Part A, EPA/540/5-91/003b, PB92-115328; Technology Evaluation Vol. II, Part B, EPA/540/5-91/003c, PB92-115336; Applications Analysis, EPA/540/A5-91/003; Technology Demonstration Summary, EPA/540/S5-91/003; and Demonstration Bulletin, EPA/540/M5-91/003.

EPA, 1992. *A Citizen's Guide to Soil Washing,* EPA, OSWER, Washington, DC, EPA/542/F-92/003.

EPA, 1992. *Bergmann USA—Soil/Sediment Washing System,* EPA RREL, Demonstration Bulletin, EPA/540/MR-92/075.

EPA, 1993. *Bescorp Soil Washing System Battery Enterprises Site—Brice Environmental Services, Inc*, EPA RREL, Demonstration Bulletin, EPA/540/MR-93/503.

EPA, 1993. *Biogenesis Soil Washing Technology,* EPA RREL, series includes Demonstration Bulletin, EPA/540/MR-93/510; Innovative Technology Evaluation Report, EPA/540/R-93/510; and Site Technology Capsule, EPA/540/SR-93/510.

Raghavan, R., D.H. Dietz, and E. Coles, 1988. *Cleaning Excavated Soil Using Extraction Agents: A State-of-the-Art Review,* EPA Report EPA 600/2-89/034.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Toronto Port Industrial Dist. Ontario, Canada	Dennis Lang Toronto Harbor Comm. 60 Harbour St. Toronto, CA M5J 1B7 (416) 863-2047 Fax: (416) 863-4830	Soil washing (volume reduction), metal dissolution, and chemical hydrolysis with biodegradation (organics)	52 ppm Naphthalene ; 10 ppm benzo(a)-pyrene	<5; 2.6	NA
Montclair Superfund Site Montclair, NJ	Mike Eagle EPA, Office of Radiation Programs 401 M St., SW, ANR-461 Washington, DC 20460 (202) 233-9376	Attrition mills, classifiers, and filter press to reduce the amount of low-level radioactive waste to be disposed of, 56% volume reduction	NA	11 pCi/g	$300/hour
Excalibur Technology	Norma Lewis EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7665	Bench scale—Soil washing and catalytic ozone oxidation Site demo scheduled for Coleman Evans, Florida	20,000 ppm total capacity	NA	$92 to $170/m^3 ($70-$130/yd^3)
Alaskan Battery Enterprises Superfund Site, Fairbanks, AK	Hugh Masters EPA RREL 2890 Woodbridge Ave. Building 10 Edison, NJ	Pilot scale, featuring gravity separation and particle size classification	2,280-10,374 ppm lead	15-2,541 ppm	
Twin Cities AAP New Brighton, MN	Michael D. Royer EPA RREL 2890 Woodbridge Ave. Building 10 Edison, NJ (908) 321-6633	Full scale, featuring gravity separation, particle size classification, metal leaching, and lead recovery	Demonstra-tion is in progress. Field work completed but laboratory work not complete.	Targets for back-ground remedia-tion: Cr, Cu, Hg, and Ni. Some batches reached state remedia-tion goals.	NA
Escambia Wood Treating Company Superfund Site, Pensacola, FL	Terri Richardson EPA RREL 26 West M.L. King Dr. Cincinnati, OH	Pilot scale, featuring particle size classification and surfactant addition	550-1,700 ppm PAHs 48-210 ppm PCP	45 ppm PAHs 3 ppm PCPs	$151/metric ton ($137/ton) (projected)
Macgill & Gibbs New Brighton, MN BioTrol	Dennis Chilcote BioTrol, Inc. 10300 Valley View Rd. Eden Prairie, MN 55344-3456 (612) 942-8032	Soil washing (volume reduction), process water treated in a bio-reactor, fines treated in a slurry bioreactor.	130 ppm PCP, 247 ppm PAHs	98,88% removal	$168/ton

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location

Michael Gruenfeld	EPA RREL Technical Support	(908) 321-6625	2890 Woodbridge Ave. MS-104 Edison, NJ 08837-3679
S. Jackson Hubbard	EPA RREL	(513) 569-7507	26 West M.L. King Dr. Cincinnati, OH 45268
Jim Galloway Frank Snite	USAED	(313) 226-6760	Detroit, MI 48231-1027
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401
Mary K. Stinson	EPA RREL Technical Support	(908) 321-6683	2890 Woodbridge Ave. MS-104 Edison, NJ 08837-3679

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4.18 SOIL VAPOR EXTRACTION (EX SITU)

Description: Ex situ soil vapor extraction (SVE) is a full-scale technology in which soil is excavated and placed over a network of aboveground piping to which a vacuum is applied to encourage volatilization of organics. The process includes a system for handling off-gases. Advantages over its in situ counterpart (Technology Profile No. 4.6) include that the excavation process forms an increased number of passageways, shallow groundwater no longer limits the process, leachate collection is possible, and treatment is more uniform and easily monitored.

4-18 TYPICAL EX SITU SVE SYSTEM

Applicability: The target contaminant group for ex situ SVE is VOCs.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- Air emissions may occur during excavation and materials handling, possibly requiring treatment.
- High humic content or compact soil inhibits volatilization.
- As a result of air emission treatment, SVE may require treating residual liquid and spent activated carbon, increasing the project cost.
- A large amount of space is required.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Soil characteristics that

need to be determined include the concentration of the contaminants, soil type and properties (e.g., texture, moisture content, particle size, permeability, porosity, and TOC), and the presence of oil and grease. Key operating parameters include air flow rate and vacuum pressure required.

Performance Data:

An advantage of the technology over its in situ counterpart is the increased number of passageways formed by the excavation process; however, as an ex situ remedy, the excavation associated with SVE poses a potential health and safety risk to site workers through skin contact and air emissions. Personal protective equipment, at a level commensurate with the contaminants involved, is normally required during excavation operations. The time required to remediate a site using ex situ SVE is highly dependent upon the specific soil and chemical properties of the contaminated media. Cleanup of a typical site, consisting of 18,200 metric tons (20,000 tons) of contaminated media, would require 12 to 36 months. Generally, most of the hardware components are relatively well developed with repair parts readily available to minimize downtime. Typical ex situ SVE systems can be left unattended for long periods of time.

Cost:

The overall cost for ex situ SVE is under $110 per metric ton ($100 pe r ton), including the cost of excavation but excluding treatment of off -gases and collected groundwater.

References:

EPA, 1990. *State of Technology Review: Soil Vapor Extraction System Technology*, EPA Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, EPA/600/2-89/024.

EPA, 1991. *AWD Technologies, Inc.—Integrated Vapor Extraction and Steam Vacuum Striping*, EPA RREL, series includes Applications Analysis, EPA/540/A5-91/002, PB92-218379; and Demonstration Bulletin, EPA/540/M5-91/002.

Points of Contact:

Contact	Government Agency	Phone	Location
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.19 SOLIDIFICATION/STABILIZATION (EX SITU)

Description: As for in situ solidification/stabilization (S/S) (see Technology Profile No. 4.7), ex situ S/S contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization). Ex situ S/S, however, typically requires disposal of the resultant materials.

4-19 TYPICAL EX SITU SOLIDIFICATION/STABILIZATION PROCESS FLOW DIAGRAM

Applicability: The target contaminant group for ex situ S/S is inorganics, including radionuclides. The technology has limited effectiveness against SVOCs and pesticides; however, systems designed to be more effective against organic contaminants are being developed and tested.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Environmental conditions may affect the long-term immobilization of contaminants.
- Some processes result in a significant increase in volume (up to double the original volume).
- Certain wastes are incompatible with different processes. Treatability studies are generally required.

- VOCs are generally not immobilized.
- Long-term effectiveness has not been demonstrated for many contaminant/process combinations.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Soil parameters that must be determined include particle size, Atterberg limits, moisture content, metal concentrations, sulfate content, organic content, density, permeability, unconfined compressive strength, leachability, microstructure analysis, and physical and chemical durability.

Performance Data: Depending upon the original contaminants and the chemical reactions that take place in the ex situ S/S process, the resultant stabilized mass may have to be handled as a hazardous waste. For certain types of radioactive waste, the stabilized product must be capable of meeting stringent waste form requirements for disposal (e.g., Class B or Class C low level materials). Remediation of a site consisting of 18,200 metric tons (20,000 tons) could require less than 1 month, depending on equipment size and type and soil properties (e.g., percent solids and particle size).

DOE has demonstrated the Polyethylene Encapsulation of Radionuclides and Heavy Metals (PERM) process at the bench scale. The process is a waste treatment and stabilization technology for high-level mixed waste. Specific targeted contaminants include radionuclides (e.g., cesium, strontium, and cobalt), and toxic metals (e.g., chromium, lead, and cadmium). The process should be ready for implementation in FY95.

Cost: Ex situ solidification/stabilization processes are among the most mature remediation technologies. Representative overall costs from more than a dozen vendors indicate an approximate cost of under $110 per metric ton ($100 per ton), including excavation.

References:

Bricka, R.M., et al., 1988. *An Evaluation of Stabilization/Solidification of Fluidized Bed Incineration Ash (K048 and K051)*, USAE-WES Technical Report EL-88-24.

EPA, 1989. *Chemfix Technologies, Inc.—Chemical Fixation/Stabilization*, EPA RREL, Technology Evaluation Vol. I, EPA/540/5-89/011a, PB91-127696; and Technology Evaluation Vol. II, EPA/540/5-89/011b, PB90-274127.

EPA, 1989. *Harcon—Solidification*, EPA RREL, series includes Technology Evaluation Vol. I, EPA/540/5-89/001a, PB89-158810; Technology Evaluation Vol. II, EPA/540/5-89/001b, PB89-158828; Applications Analysis, EPA/540/A5-89/001; and Technology Demonstration Summary,

EPA/540/S5-89/001.

EPA, 1989. *Solidtech, Inc.—Solidification*, EPA RREL, series includes Technology Evaluation Vol. I, EPA/540/5S-89/005a; Technology Evaluation Vol. II, EPA/540/5S-89/005b, PB90-191768; Applications Analysis, EPA/540/A5-89/005; Technology Demonstration Summary, EPA/540/S5-89/005; and Demonstration Bulletin, EPA/540/M5-89/005.

EPA, 1989. *Stabilization/Solidification of CERCLA and RCRA Wastes — Physical Tests, Chemical Testing Procedures, Technology Screening and Field Activities*, EPA, ORD, Washington, DC, EPA/625/6-89/022.

EPA, 1992. *Silicate Technology Corporation—Solidification/Stabilization of Organic/Inorganic Contaminants*, EPA RREL, Demonstration Bulletin, EPA/540/MR-92/010; Applications Analysis, EPA/540/AR-92/010, PB93-172948.

EPA, 1993. *Solidification/Stabilization and Its Application to Waste Materials*, Technical Resource Document, EPA, ORD, Washington, DC, EPA/530/R-93/012.

EPA, 1993. *Solidification/Stabilization of Organics and Inorganics*, Engineering Bulletin, EPA, ORD, Cincinnati, OH, EPA/540/S-92/015.

DOE, 1993. *Technology Name: Polyethylene Encapsulation*, Technology Information Profile (Rev. 2) for ProTech, DOE ProTech Database, TTP Reference No. BH-321201.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Portable Equipment Salvage Clackamas, OK	Edwin Barth - EPA CERI	Dry alumina, calcium, and silica blended in reaction vessel.	NA	93.2 to >99.9% reduction of Cu, Pb, and Zn TCLP levels	$80/metric ton ($73/ton)
Naval Construction Battalion Center Port Hueneme, CA	NFESC Code 411 Port Hueneme, CA 93043 (614) 424-5442	Spent blasting abrasives screened and mixed with portland cement and soluble silicates.	NA	<5 ppm TCLP	$94/metric ton ($85/ton)
Robins AFB Macon, GA	Terry Lyons EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7589	Addition of pozzolonic cementitious materials.	NA	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Edwin Barth	EPA CERI	(513) 569-7669 Fax: (513) 569-7585	26 West M.L. King Dr. Cincinnati, OH 45268
Mark Bricka	USAE-WES	(601) 634-3700	CEWES-EE-S 3909 Halls Ferry Road Vicksburg, MS 39180-6199
Patricia M. Erikson	EPA RREL	(513) 569-7884 Fax: (513) 569-7676	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401
Sherry Gibson	DOE	(301) 903-7258	EM-552, Trevion II Washington, DC 20585

4.20 SOLVENT EXTRACTION

Description: 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. The technology uses an organic chemical as a solvent and differs from soil washing, which generally uses water or water with wash-improving additives. Commercial-scale units are in operation; they vary in regard to the solvent employed, type of equipment used, and mode of operation.

4-20 TYPICAL SOLVENT EXTRACTION PROCESS

Solvent extraction is commonly used in combination with other technologies, such as solidification/stabilization, incineration, or soil washing, depending upon site-specific conditions. It also can be used as a standalone technology in some instances. Organically bound metals can be extracted along with the target organic contaminants, thereby creating residuals with special handling requirements. Traces of solvent may remain within the treated soil matrix, so the toxicity of the solvent is an important consideration. The treated media are usually returned to the site after having met Best Demonstrated Available Technology (BDAT) and other standards.

Applicability: Solvent extraction has been shown to be effective in treating sediments, sludges, and soils containing primarily organic contaminants such as PCBs, VOCs, halogenated solvents, and petroleum wastes. The technology is generally not used for extracting inorganics (i.e., acids, bases, salts, or 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.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Organically bound metals can be extracted along with the target organic pollutants, which restricts handling of the residuals.
- The presence of detergents and emulsifiers can unfavorably influence the extraction performance.
- Traces of solvent may remain in the treated solids; the toxicity of the solvent is an important consideration.
- Solvent extraction is generally least effective on very high molecular weight organic and very hydrophilic substances.
- Some soil types and moisture content levels will adversely impact process performance.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). It is important 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.

Soil properties that should be determined include particle size; pH; partition coefficient; cation exchange capacity; organic content; TCLP; moisture content; and the presence of metals, volatiles, clays, and complex waste mixtures.

Performance Data: The performance data currently available are mostly from Resource Conservation Company (RCC). The ability of RCC's full-scale B.E.S.T.? process to separate oily feedstock into product fractions was evaluated by EPA at the General Refining Superfund site near Savannah, Georgia, in February 1987. The treated soils from this unit were backfilled 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.

Cost: Cost estimates for this technology range from $110 to $440 per metric ton ($100 to $400 per ton).

References:

EPA, 1988. *Evaluation of the B.E.S.T.? Solvent Extraction Sludge Treatment Technology Twenty-Four Hour Test*, EPA/600/2-88/051.

EPA, 1988. *Technology Screening Guide for Treatment of CERCLA Soils and Sludges — Appendix B.1: Chemical Extraction*, EPA, Washington, DC, EPA/540/2-88/004.

EPA, 1989. *Innovative Technology: B.E.S.T.? Solvent Extraction Process*, OSWER Directive 9200.5-253FS.

EPA, 1990. *CF Systems Organics Extraction Process New Bedford Harbor, MA, Applications Analysis Report*, Superfund Innovative Technology Evaluation, Washington, DC, EPA/540/A5-90/002. Available from NTIS, Springfield, VA, Order No. PB91-1133845.

EPA, 1990. *CF Systems Corp.—Solvent Extraction*, EPA RREL, series includes Technology Evaluation Vol. I, 540/5-90/001; Technology Evaluation Vol. II, EPA/540/5-90/002a, PB90-186503; Application Analysis, EPA/540/A5-90/002; and Technology Demonstration Summary, EPA/540/S5-90/002.

EPA, 1990. *Solvent Extraction Treatment*, Engineering Bulletin, EPA, OERR and ORD, Washington, DC, EPA/540/2-90/013.

EPA, 1993. *Terra Kleen Solvent Extraction Technology—Terra Kleen Response Group, Inc.*, EPA RREL, Demonstration Bulletin, EPA/540/MR-94/521.

Raghavan, R., D.H. Dietz, and E. Coles, 1988. *Cleaning Excavated Soil Using Extraction Agents: A State-of-the-Art Review*, EPA Releases Control Branch, Edison, NJ, EPA Report EPA 600/2-89/034.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Port Arthur, TX	NA	Full-scale 50-tpd refinery sludge treatment unit	2,575 ppm PCB	90% reduction	NA
Conroe, TX	NA	Oil and grease and aromatic priority pollutants	2,879 ppm PAH	122 ppm PAH	NA
General Refining Savannah, GA (Superfund)	NA	Transportable B.E.S.T. unit to treat 4 acidic oily sludge ponds	10,000 ppm Pb, 190 ppm Cu, 5 ppm PCBs	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Michael Gruenfeld	EPA RREL	FTS 340-6625 (201) 321-6625	GSA Raritan Depot Woodbridge Avenue Edison, NJ 08837
Mark Bricka or Danny Averette	USAE WES	(601) 636-3111	Attn: CEWES-EE-S 3909 Halls Ferry Road Vicksburg, MS 39180-6199
Laurel Stanley or Mark Meckes	EPA RREL	(513) 569-7863	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.21 HIGH TEMPERATURE THERMAL DESORPTION

Description: High temperature thermal desorption (HTTD) is a full-scale technology in which wastes are heated to 320 to 560 ?C (600 to 1,000 ?F) to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system. HTTD systems are physical separation processes and are not designed to destroy organics. Bed temperatures and typical residence times will cause selected contaminants to volatilize but not be oxidized.

4-21 TYPICAL HIGH TEMPERATURE THERMAL DESORPTION PROCESS

HTTD is frequently used in combination with incineration, solidification/stabilization, or dechlorination, depending upon site-specific conditions.

The technology has proven it can produce a final contaminant concentration level below 5 mg/kg for the target contaminants identified.

Applicability: The target contaminants are SVOCs, PAHs, PCBs, and pesticides; however, HTTD systems have varying degrees of effectiveness against the full spectrum of organic contaminants. VOCs and fuels also may be treated, but treatment may be less cost-effective. Volatile metals may be removed by HTTD systems. The presence of chlorine can affect the volatilization of some metals, such as lead. 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.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Feed particle size greater than 2 inches can impact applicability or cost at specific sites.
- Dewatering may be necessary to reduce the amount of energy required to heat the soil.
- Highly abrasive feed can potentially damage the processor unit.
- Clay and silty soils and high humic content soils increase reaction time as a result of binding of contaminants.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). In addition to identifying soil contaminants and their concentrations, information necessary for engineering thermal systems to specific applications include soil moisture content and classification (no sieve analysis is necessary), determination of boiling points for various compounds to be removed, and treatability tests to determine the efficiency of thermal desorption for removing various contaminants at various temperatures and residence times.

Performance Data: There are at least five vendors actively promoting the technology, and most of the hardware components for HTTD systems are readily available off the shelf. The time to complete cleanup of the "standard" 18,200-metric ton (20,000-ton) site using HTTD is just over 4 months.

Cost: Approximate overall cost is between $110 and $330 per metric ton ($100 and $300 per ton).

References:

Anderson, W.C., 1993. *Innovative Site Remediation Technology— Thermal Desorption*, American Academy of Environmental Engineers.

EPA, 1988. *Shirco—Infrared Incineration*, EPA RREL, series includes Technology Evaluation—Peake Oil, EPA/540/5-88/002a; Technology Evaluation—Rose Township, EPA/540/5-89/007a; Technology Evaluation—Rose Township Vol. II, EPA/540/5-89/007b, PB89-167910; Applications Analysis, EPA/540/S5-89/010; Technology Demonstration Summary, EPA/540/S5-89/007; Demonstration Bulletin, EPA/540/M5-88/002; and Technology Evaluation Report—Peake Oil Vol. II, EPA/540/5-88/002B, PB89-116024.

EPA, 1989. *American Combustion—Oxygen Enhanced Incineration*, EPA RREL, series includes Technology Evaluation, EPA/540/5-89/008; Applications Analysis, EPA/540/A5-89/008; Technology Demonstration Summary, EPA/540/S5-89/008; and Demonstration Bulletin, EPA/540/M5-89/008.

EPA, 1992. *Ogden Circulating Bed Combustor—McCall Superfund Site*, EPA RREL, Technology Evaluation, EPA/540/R-92/001; and Demonstration Bulletin, EPA/540/MR-92/001.

EPA, 1993. *X-TRAX Model 100 Thermal Desorption System Chemical Waste Management*, EPA RREL, Demonstration Bulletin, EPA/540/MR-93/502.

EPA, 1994. *Thermal Desorption Treatment*, Engineering Bulletin, EPA, OERR and ORD, Washington, DC, EPA/540/5-94/501.

Johnson, N.P., J.W. Noland, and P.J. Marks, 1987. *Bench-Scale Investigation of Low Temperature Thermal Stripping of Volatile Organic Compounds From Various Soil Types: Technical Report*, AMXTH-TE-CR-87124, USATHAMA.

Marks, P.J. and J.W. Noland, 1986. *Economic Evaluation of Low Temperature Thermal Stripping of Volatile Organic Compounds from Soil, Technical Report*, AMXTH-TE-CR-86085, USATHAMA.

McDevitt, N.P., J.W. Noland, and P.J. Marks, 1986. *Bench-Scale Investigation of Air Stripping of Volatile Organic Compounds from Soil: Technical Report*, AMXTH-TE-CR-86092, USATHAMA.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Alaskan Battery Enterprises Superfund Site, Fairbanks, AK	Hugh Masters EPA RREL 2890 Woodbridge Ave. Building 10 Edison, NJ	Pilot scale, featuring gravity separation and particle size classification.	2,280-10,374 ppm lead	15-2,541 ppm lead	$182/metric ton ($165/ton)
Escambia Wood Treating Company Superfund Site, Pensacola, FL	Terri Richardson EPA RREL 26 West M.L. King Dr. Cincinnati, OH	Pilot scale, featuring particle size classification and surfactant addition.	550-1,700 ppm PAHs 48-210 ppm PCP	45 ppm PAHs, 3 ppm PCPs	$151/metric ton ($137/ton) (projected)

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Michael Gruenfeld	EPA RREL Releases Control Branch	FTS 340-6625 (908) 321-6625	2890 Woodbridge Avenue Building 10 (MS-104) Edison, NJ 08831
Daniel E. Averett	USAE-WES	(601) 634-3959	Attn: CEWES-EE-S 3909 Halls Ferry Road Vicksburg, MS 39180-6199
Paul dePercin	EPA RREL Demonstration Section	(513) 569-7797	26 West M.L. King Dr. Cincinnati, OH 45267
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.22 HOT GAS DECONTAMINATION

Description: The process involves raising the temperature of the contaminated equipment or material to 260 ?C (500 ?F) for a specified period of time. The gas effluent from the material is treated in an afterburner system to destroy all volatilized contaminants. The method eliminates a waste that currently is stockpiled and requires disposal as a hazardous material. This method will permit reuse or disposal of scrap as nonhazardous material. Consideration is being given to applying the hot gases to explosives-contaminated underground piping in situ.

Hot gas decontamination can also be used for decontamination of explosives-contaminated masonry or metallic structures. The method involves sealing and insulating the structures, heating with hot gas stream to 260 ?C (500 ?F) for a prescribed period of time, volatilizing the explosive contaminants, and destroying them in an afterburner. Operating conditions are site-specific. Contaminants are completely destroyed.

4-22 TYPICAL PROCESS FLOW DIAGRAM FOR HOT GAS DECONTAMINATION OF EXPLOSIVES-CONTAMINATED EQUIPMENT

Applicability: The method is applicable for process equipment requiring decontamination for reuse. It is also applicable for explosive items, such as mines and shells, being demilitarized (after removal of explosives) or scrap material contaminated with explosives.

The method can also be used for buildings or structures associated with ammunition plants, arsenals, and depots involved in the manufacture, processing, loading, and storage of pyrotechnics, explosives, and propellants.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- The costs of this method are higher than open burning.
- Flash chamber design must take into consideration possible explosions from improperly demilitarized mines or shells.
- The rate at which equipment or material can be decontaminated is slower than that for open burning.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Specific data required to evaluate the potential use of hot gas decontamination include:

- Types of explosives present.
- Weight of the explosives present.

Performance Data: Items decontaminated for 6 hours at a minimum temperature of 260 ?C (500 ?F) were found to be safe for public release as scrap. TNT destruction rates of 99.99% can be achieved.

Cost: The cost of the decontamination will vary with the application, depending upon the size and geometry of the equipment or material to be decontaminated and the temperature and holding time required for the decontamination. No specific cost analysis has been completed.

References:

Maumee Research and Engineering, April 1986. *Design Support for a Hot Gas Decontamination System for Explosives-Contaminated Buildings.*

McNeill, W., et al., October 1987. *Pilot Plant Testing of Hot Gas Building Decontamination Process - Final Report,* USATHAMA Report AMXTH-TE-CR-87130.

USATHAMA, July 1990. *Pilot Test of Hot Gas Decontamination of Explosives-Contaminated Equipment at Hawthorne Army Ammunition Plant (HWAAP), Hawthorne, NV, Final Technical Report,* USATHAMA Report CETHA-TE-CR-90036.

Woodland, L.R., et al., August 1987. *Pilot Testing of Caustic Spray/Hot Gas Building Decontamination Process,* USATHAMA Report AMHTH-TE-CR-87112.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
HWAAP Hawthorne, NV	Erik B. Hangeland USAEC ETD APG, MD 21010 (410) 671-2054	Successful pilot-scale demonstration	NA	99.99% removal of TNT	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.23 INCINERATION

Description: High temperatures, 870 to 1,200 ?C (1,400 to 2,200 ?F), are used to volatilize and combust (in the presence of oxygen) halogenated and other refractory organics in hazardous wastes. The destruction and removal efficiency (DRE) for properly operated incinerators exceeds the 99.99% requirement for hazardous waste and can be operated to meet the 99.9999% requirement for PCBs and dioxins.

4-23 TYPICAL MOBILE/TRANSPORTABLE INCINERATION PROCESS

Commercial incinerator designs are rotary kilns, equipped with an afterburner, a quench, and an air pollution control system. The rotary kiln is a refractory-lined, slightly-inclined, rotating cylinder that serves as a combustion chamber and operates at temperatures up to 980 ?C (1,800 ?F).

An experimental unit, the circulating fluidized bed (CFB), uses high-velocity air to circulate and suspend the waste particles in a combustion loop and operates at temperatures up to 870 ?C (1,600 ?F). Another experimental unit, the infrared unit uses electrical resistance heating elements or indirect-fired radiant U-tubes to heat material passing through the chamber on a conveyor belt and operates at temperatures up to 870 ?C (1,600 ?F).

Incinerator off-gas requires treatment by an air pollution-control system to remove particulates and neutralize and remove acid gases (HCl, NO_x, and

SO_x). Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed-bed scrubbers and spray driers remove acid gases. Limestone or caustic solution added to the combustor loop removes acid gases in the CFB.

Incineration, primarily off-site, has been selected or used as the remedial action at more than 150 Superfund sites. Incineration is subject to a series of technology-specific regulations, including the following federal requirements: CAA (air emissions), TSCA (PCB treatment and disposal), RCRA (hazardous waste generation, treatment, storage, and disposal), NPDES (discharge to surface waters), and NCA (noise).

Applicability: Incineration is used to remediate soils contaminated with explosives and hazardous wastes, particularly chlorinated hydrocarbons, PCBs, and dioxins.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Only one off-site incinerator is permitted to burn PCBs and dioxins.
- There are specific feed size and materials handling requirements that can impact applicability or cost at specific sites.
- Heavy metals can produce a bottom ash that requires stabilization.
- Volatile heavy metals, including lead, cadmium, mercury, and arsenic, leave the combustion unit with the flue gases and require the installation of gas cleaning systems for removal.
- 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. Such compounds are likely to be short-lived reaction intermediates that can be destroyed in a caustic quench.
- Sodium and potassium form low melting point ashes that can attack the brick lining and form a sticky particulate that fouls gas ducts.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). In addition to identifying soil contaminants and their concentrations, information necessary for engineering thermal systems to specific applications includes soil moisture content and classification (no sieve analysis is necessary), the soil fusion temperature, and the soil heating value.

Performance Data: If an off-site incinerator is used, the potential risk of transporting the hazardous waste through the community must be considered. Approximately 20 commercial RCRA-permitted hazardous waste incinerators and approximately 10 transportable high temperature units are operating. The commercial units are large capacity rotary kilns with afterburners and sophisticated air pollution control systems.

Cost: Soil treatment costs at off-site incinerators range from $220 to $1,100 per metric ton ($200 to $1,000 per ton) of soil, including all project costs. Mobile units that can be operated on-site will reduce soil transportation costs. Soils contaminated with PCBs or dioxins cost $1,650 to $6,600 per metric ton ($1,500 to $6,000 per ton) to incinerate.

References:

EPA, 1987. *Incineration of Hazardous Waste,* Fact Sheet, EPA, Office of Solid Waste, Washington, DC, EPA/530-SW-88-018.

EPA, 1988. *Experience in Incineration Applicable to Superfund Site Remediation,* EPA, RREL and Center for Environmental Research Information, EPA/625/9-88/008.

EPA, 1988. *Hazardous Waste Incineration: Questions and Answers,* EPA, Office of Solid Waste, Washington, DC, EPA/530/SW-88/018.

EPA, 1990. *Mobile/Transportable Incineration Treatment,* Engineering Bulletin, EPA, OERR and ORD, Washington, DC, EPA/540/2-90/014.

EPA, 1988. *Shirco—Infrared Incineration,* EPA RREL, series includes Technology Evaluation—Peake Oil, EPA/540/5-88/002a; Technology Evaluation—Rose Township, EPA/540/5-89/007a; Technology Evaluation—Rose Township Vol. II, EPA/540/5-89/007b, PB89-167910; Applications Analysis, EPA/540/S5-89/010; Technology Demonstration Summary, EPA/540/S5-89/007; Demonstration Bulletin, EPA/540/ M5-88/002; and Technology Evaluation Report—Peake Oil Vol. II, EPA/540/5-88/002B, PB89-116024.

EPA, 1989. *American Combustion—Oxygen Enhanced Incineration,* EPA RREL, series include Technology Evaluation, EPA/540/5-89/008; Applications Analysis, EPA/540/A5-89/008; Technology Demonstration Summary, EPA/540/S5-89/008; and Demonstration Bulletin, EPA/540/M5-89/008.

EPA, 1992. *Ogden Circulating Bed Combustor—McCall Superfund Site,* EPA RREL, Technology Evaluation, EPA/540/R-92/001; Demonstration Bulletin, EPA/540/MR-92/001.

EPA, 1993. *X-TRAX Model 100 Thermal Desorption System Chemical Waste Management,* EPA RREL, Demonstration Bulletin, EPA/540/MR-93/502.

Noland, J.W., et al., 1984. *Task 2: Incineration Test of Explosives Contaminated Soils at Savanna Army Depot Activity, Final Report, Savanna Illinois*, USATHAMA Report DRXTH-TE-CR 84277.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Peak Oil Site Tampa, FL	Howard O. Wall EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7691	Full scale: electric infrared mobile incineration unit	Oil sludge (PCBs and lead)	NA	$180 to $800/metric ton ($164-$730/ton)
Savanna AD Savanna, IL	Michael G. Cosmos Roy F. Weston, Inc. One Weston Way West Chester, PA 19380 (610) 701-7423	Full scale transportable incineration system- 75,000 tons of soil	1,000 ppm TNT	<1 ppm	$180/metric ton ($173/ton) inclusive
Lauder Salvage Yard Beardstown, IL	Michael G. Cosmos Roy F. Weston, Inc. One Weston Way West Chester, PA 19380 (610) 701-7423	Full scale transportable incineration system	12,000 ppm PCBs	<1 ppm	$200/metric ton ($180/ton)

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Donald A. Oberacker	EPA RREL	FTS 684-7510 (513) 569-7510	26 West M.L. King Dr. Cincinnati, OH 45268
Joseph McSorley	EPA Air & Energy ERL	(919) 541-2920	Alexander Dr. Research Triangle Park, NC 17711
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.24 LOW TEMPERATURE THERMAL DESORPTION

Description: Low temperature thermal desorption (LTTD) systems are physical separation processes and are not designed to destroy organics. Wastes are heated to between 90 and 320 ?C (200 to 600 ?F) to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system. The bed temperatures and residence times designed into these systems will volatilize selected contaminants but will typically not oxidize them. LTTD is a full-scale technology that has been proven successful for remediating petroleum hydrocarbon contamination in all types of soil. Contaminant destruction efficiencies in the afterburners of these units are greater than 95%. The same equipment could probably meet stricter requirements with minor modifications, if necessary. Decontaminated soil retains its physical properties and ability to support biological activity.

4-24 TYPICAL SCHEMATIC DIAGRAM OF THERMAL DESORPTION PROCESS

Two common thermal desorption designs are the rotary dryer and thermal screw. Rotary dryers are horizontal cylinders that can be indirect- or direct-fired. The dryer is normally inclined and rotated. For the thermal screw units, screw conveyors or hollow augers are used to transport the medium through an enclosed trough. Hot oil or steam circulates through the auger to indirectly heat the medium. All thermal desorption systems require treatment

of the off-gas to remove particulates and contaminants. Particulates are removed by conventional particulate removal equipment, such as wet scrubbers or fabric filters. Contaminants are removed through condensation followed by carbon adsorption, or they are destroyed in a secondary combustion chamber or a catalytic oxidizer. Most of these units are transportable.

Applicability: The target contaminant groups for LTTD systems are nonhalogenated VOCs and fuels. The technology can be used to treat SVOCs at reduced effectiveness.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- There are specific feed size and materials handling requirements that can impact applicability or cost at specific sites.
- Dewatering may be necessary to achieve acceptable soil moisture content levels.
- Highly abrasive feed potentially can damage the processor unit.
- Heavy metals in the feed may produce a treated solid residue that requires stabilization.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). In addition to identifying soil contaminants and their concentrations, information necessary for engineering thermal systems to specific applications include soil moisture content and classification, texture, mercury content, pH, and presence of high or low volatility compounds.

Performance Data: Most of the hardware components for LTTD systems are readily available off the shelf. Many vendors offer LTTD units mounted on a single trailer. Soil throughput rates are typically 13 to 18 metric tons (15 to 20 tons) per hour for sandy soils and less than 6 metric tons (7 tons) per hour for clay soils when more than 10% of the material passes a 200-mesh screen. Units with capacities ranging from 23 to 46 metric tons (25 to 50 tons) per hour require four or five trailers for transport and 2 days for setup.

All ex situ soil thermal treatment systems employ similar feed systems consisting of a screening device to separate and remove materials greater than 5 centimeters (2 inches), a belt conveyor to move the screened soil from the screen to the first thermal treatment chamber, and a weight belt to measure soil mass. Occasionally, augers are used rather than belt conveyors, but either type of system requires daily maintenance and is subject to failures that shut the system down. Soil conveyors in large systems seem more prone to failure than those in smaller systems. Size reduction equipment can be

incorporated into the feed system, but its installation is usually avoided to minimize shutdown as a result of equipment failure.

Soil storage piles and feed equipment are generally covered as protection from rain to minimize soil moisture content and material handling problems. Soils and sediments with water contents greater than 20 to 25% may require the installation of a dryer in the feed system to reduce the energy cost to heat the soil. Some volatilization of contaminants occurs in the dryer, and the gases are routed to a thermal treatment chamber.

Cost:

Rates charged to remediate petroleum hydrocarbon contaminated soil range from $45 to $110 per metric ton ($40 to $100 per ton) of soil. Costs for remediating clay soils may approach $220 per metric ton ($200 per ton) because of the reduced throughout resulting from the small soil particle size. Of this cost, approximately $20 to $35 per metric ton ($15 to $30 per ton) is required for direct operating costs such as utility consumption and repair. Vendors typically perform preventive maintenance, such as lubrication, on a daily basis. Unit transportation and setup costs are typically $3.30 to $5.50 per metric ton ($3 to $5 per ton), seldom exceeding a mobilization cost of $200,000. Excavation of contaminated soil and the replacement of the treated soil costs approximately $6 to $11 per metric ton ($5 to $10 per ton).

References:

EPA, 1992. *A Citizen's Guide to Thermal Desorption*, EPA, OSWER, Washington, DC, EPA/542/F-92/006.

EPA, 1992. *Low Temperature Thermal Treatment (LT^3®) System*, Demonstration Bulletin, Washington, DC, EPA/540/MR-92/019.

EPA, 1992. *Roy F. Weston, Inc.—Low Temperature Thermal Treatment (LT3) System*, EPA RREL, Demonstration Bulletin, EPA/540/MR-92/019; and Applications Analysis, EPA/540/AR-92/019.

EPA, 1993. *Low Temperature Thermal Aeration (LTTA) System, Canonie Environmental Services, Inc*, EPA RREL, Demonstration Bulletin, EPA/540/MR-93/504.

EPA, 1994. *Thermal Desorption System, Clean Berkshires, Inc*, EPA RREL, Demonstration Bulletin, EPA/540/MR-94/507; and Capsule, EPA/540/R-94/507a.

EPA, 1994. *Thermal Desorption Treatment*, Engineering Bulletin, EPA/540/5-94/501.

EPA, 1994. *Thermal Desorption Unit, Eco Logic International, Inc*., EPA RREL, Demonstration Bulletin, EPA/540/MR-94/504.

Lighty, J., et al., 1987. *The Cleanup of Contaminated Soil by Thermal Desorption*, Presented at Second International Conference on New Frontiers for Hazardous Waste Management, EPA Report EPA/600/9-87/018.

U.S. Army, August 1990. *The Low Temperature Thermal Stripping Process*, USATHAMA, APG, MD, USATHAMA Cir. 200-1-5.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Tinker AFB Oklahoma City, OK	Michael G. Cosmos Roy F. Weston, Inc. One Weston Way West Chester, PA 19380 (610) 701-7423	Low temperature thermal treatment (LT^3) - 3,000 yd^3 treated - VOCs, SVOCs, TP-4	NA	99.9% BTEX removal	$410 to $798/metric ton ($373-$725/ton) based on soil moisture
Letterkenny AD Chambersburg, PA	Michael G. Cosmos Roy F. Weston, Inc. One Weston Way West Chester, PA 19380 (610) 701-7423	USAEC's Holo-Flite screw thermal processor	Various VOCs up to 20,000 ppm	99.95% VOC removal	$81 to $176/metric ton ($74-$160/ton) + $410 to $798/metric ton ($87-$184/ton) soil for gas treat-ment
Letterkenny AD Chambersburg, PA	Michael G. Cosmos Roy F. Weston, Inc. One Weston Way West Chester, PA 19380 (610) 701-7423	LT^3 - TCE, DCE, PCE, xylene	Various VOCs up to 27,000 ppm	Up to 1.8 ppm	$410 to $798/metric ton ($373-$725/ton) based on soil moisture

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Michael Gruenfeld	EPA RREL Releases Control Branch	(908) 321-6625	2890 Woodbridge Ave. Building 10 (MS-104) Edison, NJ 08837
Paul dePercin	EPA	(513) 569-7797	26 West M.L. King Dr. Cincinnati, OH 45268
Daniel E. Averett	USAE-WES	(601) 634-3959	Attn: CEWES-EE-S 3909 Halls Ferry Road Vicksburg, MS 39180-6199
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.25 OPEN BURN/OPEN DETONATION

Description: Open burn (OB) and open detonation (OD) operations are conducted to destroy unserviceable, unstable, or unusable munitions and explosives materials. In OB operations, explosives or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as flame, heat, or a detonation wave (that does not result in a detonation). In OD operations, detonatable explosives and munitions are destroyed by a detonation, which is initiated by the detonation of a disposal charge.

OB/OD operations can destroy many types of explosives, pyrotechnics, and propellants. OB areas must be able to withstand accidental detonation of any or all explosives being destroyed, unless the operating OB technicians recognize that the characteristics of the materials involved are such that orderly burning without detonation can be ensured. Personnel with this type of knowledge must be consulted before any attempt is made at OB disposal, especially if primary explosives are present in any quantity.

4-25 TYPICAL OPEN BURNING PAN AND CAGE

OB and OD can be initiated either by electric or burning ignition systems. In general, electric systems are preferable because they provide better control over the timing of the initiation. In an electric system, electric current heats a bridge wire, which ignites a primary explosive or pyrotechnic, which, in turn,

ignites or detonates the material slated to be burned or detonated. If necessary, safety fuses, which consists of propellants wrapped in plastic weather stripping, are used to initiate the burn or detonation.

Applicability: OB/OD can be used to destroy unserviceable, unstable, or unusable munitions and explosive materials.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- Minimum distance requirements for safety purposes mean substantial space is required.
- OB/OD operations emissions are difficult to capture for treatment and may not be permitted in areas with emissions limitations.
- OB/OD operations require that prevailing winds carry sparks, flame, smoke, and toxic fumes away from neighboring facilities. OB/OD operations are never conducted during sand, snow, or electrical storms strong enough to produce static electricity, which might cause premature detonation.
- In addition, with growing OB/OD restriction, DOD's ability to treat energetic wastes is diminishing and energetics disposal may be eliminated.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Specific data required to evaluate the potential use of OB/OD operations include:

- Location plan for proposed OB/OD operations showing adjacent land uses and safety buffer zone.
- Emissions requirements for the geographic area of the OB/OD operation.

Performance Data: Several federal agencies are pursuing new technologies in this area with DOE (molten salt technology) and the U.S. Army Construction Engineering Research Laboratories (CERL) (preliminary investigations) being the most active.

Cost: Not available.

References: Teer, R.G., R.E. Brown, and H.E. Sarvis, June 1993. *Status of RCRA Permitting of Open Burning and Open Detonation of Explosive Wastes*, Presented at Air and Waste Management Association Conference, 86th Annual Meeting and Exposition, Denver, CO.

USAF, 1990. *Explosives Safety Standards,* Air Force Regulation 127-100.

USAMC (U.S. Army Materiel Command), 1985. *Explosives Safety Manual*, AMC-R, 385-100.

Points of Contact:

Contact	Government Agency	Phone	Location
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.25 OPEN BURN/OPEN DETONATION

Description: Open burn (OB) and open detonation (OD) operations are conducted to destroy unserviceable, unstable, or unusable munitions and explosives materials. In OB operations, explosives or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as flame, heat, or a detonation wave (that does not result in a detonation). In OD operations, detonatable explosives and munitions are destroyed by a detonation, which is initiated by the detonation of a disposal charge.

OB/OD operations can destroy many types of explosives, pyrotechnics, and propellants. OB areas must be able to withstand accidental detonation of any or all explosives being destroyed, unless the operating OB technicians recognize that the characteristics of the materials involved are such that orderly burning without detonation can be ensured. Personnel with this type of knowledge must be consulted before any attempt is made at OB disposal, especially if primary explosives are present in any quantity.

4-25 TYPICAL OPEN BURNING PAN AND CAGE

OB and OD can be initiated either by electric or burning ignition systems. In general, electric systems are preferable because they provide better control over the timing of the initiation. In an electric system, electric current heats a bridge wire, which ignites a primary explosive or pyrotechnic, which, in turn, ignites or detonates the material slated to be burned or detonated. If necessary, safety fuses, which consists of propellants wrapped in plastic weather stripping, are used to initiate the burn or detonation.

Applicability: OB/OD can be used to destroy unserviceable, unstable, or unusable munitions and explosive materials.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- Minimum distance requirements for safety purposes mean substantial space is required.
- OB/OD operations emissions are difficult to capture for treatment and may not be permitted in areas with emissions limitations.
- OB/OD operations require that prevailing winds carry sparks, flame,

smoke, and toxic fumes away from neighboring facilities. OB/OD operations are never conducted during sand, snow, or electrical storms strong enough to produce static electricity, which might cause premature detonation.

- In addition, with growing OB/OD restriction, DOD's ability to treat energetic wastes is diminishing and energetics disposal may be eliminated.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Specific data required to evaluate the potential use of OB/OD operations include:

- Location plan for proposed OB/OD operations showing adjacent land uses and safety buffer zone.
- Emissions requirements for the geographic area of the OB/OD operation.

Performance Data: Several federal agencies are pursuing new technologies in this area with DOE (molten salt technology) and the U.S. Army Construction Engineering Research Laboratories (CERL) (preliminary investigations) being the most active.

Cost: Not available.

References:

Teer, R.G., R.E. Brown, and H.E. Sarvis, June 1993. *Status of RCRA Permitting of Open Burning and Open Detonation of Explosive Wastes*, Presented at Air and Waste Management Association Conference, 86th Annual Meeting and Exposition, Denver, CO.

USAF, 1990. *Explosives Safety Standards,* Air Force Regulation 127-100.

USAMC (U.S. Army Materiel Command), 1985. *Explosives Safety Manual*, AMC-R, 385-100.

Points of Contact:

Contact	Government Agency	Phone	Location
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.26 PYROLYSIS

Description: Pyrolysis is formally defined as chemical decomposition induced in organic materials by heat in the absence of oxygen. In practice, it is not possible to achieve a completely oxygen-free atmosphere; actual pyrolytic systems are operated with less than stoichiometric quantities of oxygen. Because some oxygen will be present in any pyrolytic system, nominal oxidation will occur. If volatile or semivolatile materials are present in the waste, thermal desorption will also occur.

4-26 TYPICAL PYROLYSIS PROCESS

Pyrolysis transforms hazardous organic materials into gaseous components, small quantities of liquid, and a solid residue (coke) containing fixed carbon and ash. Pyrolysis of organic materials produce combustible gases, including carbon monoxide, hydrogen and methane, and other hydrocarbons. If the off-gases are cooled, liquids condense producing an oil/tar residue and contaminated water. Pyrolysis typically occurs under pressure and at operating temperatures above 430 ?C (800 ?F). The pyrolysis gases require further treatment. The off-gases may be treated in a secondary combustion chamber, flared, and partially condensed. Particulate removal equipment such as fabric filters or wet scrubbers are also required.

Pyrolysis is an emerging technology. Although the basic concepts of the process have been validated, the performance data for an emerging technology have not been evaluated according to methods approved by EPA and adhering to EPA quality assurance/quality control standards. Performance data are currently available only for vendors. Also, existing

data are limited in scope and quantity/quality and are frequently of a proprietary nature.

Applicability: The target contaminant groups for pyrolysis are SVOCs and pesticides. 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 waste.

Pyrolysis systems may be applicable to a number or organic materials that "crack" or undergo a chemical decomposition in the presence of heat. Pyrolysis has shown promise in treating organic contaminants in soils and oily sludges. Chemical contaminants for which treatment data exist include PCBs, dioxins, PAHs, and many other organics. Pyrolysis is not effective in either destroying or physically separating inorganics from the contaminated medium. Volatile metals may be removed as a result of the higher temperatures associated with the process but are similarly not destroyed.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- There are specific feed size and materials handling requirements that impact applicability or cost at specific sites.
- The technology requires drying of the soil to achieve a low soil moisture content (<1%).
- Highly abrasive feed can potentially damage the processor unit.
- High moisture content increases treatment costs.
- Treated media containing heavy metals may require stabilization.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). In addition to identifying soil contaminants and their concentrations, information necessary for engineering thermal systems to specific applications include soil moisture content and classification (no sieve analysis is necessary), and the soil fusion temperature.

Performance Data: Limited performance data are available for pyrolytic systems treating hazardous wastes containing PCBs, dioxins, and other organics. The quality of this information has not been determined. These data are included as a general indication of the performance of pyrolysis equipment and may not be directly transferrable to a specific Superfund site. Site characterization and treatability studies are essential in further refining and screening the pyrolysis technology.

Cost: The overall cost for remediating approximately 18,200 metric tons (20,000 tons) of contaminated media is expected to be approximately $330 per metric ton ($300 per ton).

References:

EPA, 1992. *AOSTRA-SoilTech Anaerobic Thermal Processor: Wide Beach Development Site*, Demonstration Bulletin, EPA, ORD, Washington, DC, EPA/540/MR-92/008.

EPA, 1992. *Pyrolysis Treatment*, Engineering Bulletin, EPA, OERR, Washington, DC, EPA/540/S-92/010.

EPA, 1992. *SoilTech Anaerobic Thermal Processor: Outboard Marine Corporation Site*, Demonstration Bulletin, EPA, ORD, Washington, DC, EPA/540/MR-92/078.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
HT-V	TDI Thermal Dynamics	Mobile thermal desorption unit with pyrolytic mode	Dioxin	99.99% removal	NA
Deutsche Babcock Anlagen AG	NA	Desorb and combust volatiles	Polycyclic aromatics	99.77% removal	NA
Wide Beach Superfund Site NY	SoilTech, Inc.	Anaerobic thermal processor (ATP), indirectly heated rotary kiln	5,000 ppm PCB	<2 ppm	$290/metric ton ($265/ton)

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Donald Oberacker	EPA RREL	(513) 569-7510	26 West M.L. King Dr. Cincinnati, OH 45268
Paul dePercin	EPA RREL	(513) 569-7797 Fax: (513) 569-7620	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.27 VITRIFICATION (EX SITU)

Description: Ex situ vitrification is designed to encapsulate inorganic contaminants, rather than reduce contaminant concentrations. Destruction of the organic contaminants present in the treated media, however, does occur because of temperatures achieved in the process.

4.27 TYPICAL EX SITU VITRIFICATION PROCESS BLOCK FLOW

Ex situ vitrification is effective in reducing the mobility of the contaminated wastes within the media. The vitrified mass has high strength and resistance to leaching. The strength properties of material vitrified by different systems can vary widely. Systems in which the vitrified mass is quench-cooled may produce a more easily fractured mass than systems in which the mass is allowed to air cool. Systems in which fluxing agents are used will also have different strength properties. The composition of the soil that is vitrified may also affect the strength properties of the vitrified material.

Ex situ vitrification is normally considered a standalone technology; however, its potential for use in treating the solid residuals from other technologies, such as incinerator ash, is receiving increasing attention.

Applicability: Ex situ vitrification is applicable to the full range of contaminant groups, but inorganics is the target contaminant group. Metals, radionuclides, etc. are encapsulated in the vitrified mass, resisting leaching for geologic time periods.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Organic off-gases need to be controlled. Some volatile heavy metal and radioactive contaminants may volatilize and require treatment in the off-gas system.

- Use or disposal of the resultant vitrified slag is required.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). In addition to identifying soil contaminants and their concentrations, information necessary for engineering thermal systems to specific applications include soil moisture content and classification (no sieve analysis is necessary), and the soil fusion temperature.

Performance Data: An EPA SITE program demonstration of plasma arc vitrification was conducted in 1991 at DOE's Component Development and Integration facility in Butte, Montana. During the demonstration, the furnace processed approximately 1,820 kilograms (4,000 pounds) of waste. The waste consisted of soil with heavy metals from the Silver Bow Creek Superfund site, spiked with 28,000-ppm zinc oxide and 1,000-ppm hexachlorobenzene and mixed in a 90-to-10 weight ratio with No. 2 diesel oil.

DOE is currently developing a full-scale prototype of a fixed hearth DC plasma torch process that will convert full drums of waste materials directly to an enhanced waste form in a one step process. An arc melter vitrification process exists but requires engineering development.

Cost: Approximate overall cost is $770 per metric ton ($700 per ton). Ex situ vitrification is a relatively complex, high-energy technology requiring a high degree of specialized skill and training.

References:

Circeo, Louis J., Ph.D., 1991. *Destruction and Vitrification of Asbestos Using Plasma Arc Technology,* Georgia Institute of Technology for USACERL, Champaign, IL.

DOE, undated. *Technology Name: Arc Melter Vitrification,* Technology Information Profile (Rev. 2) for ProTech, DOE ProTech Database, TTP Reference No.: ID-132011.

DOE, 1993. *Technology Name: Arc Melter Vitrification,* Technology Information Profile (Rev. 2) for ProTech, DOE ProTech Database, TTP Reference No.: ID-132010.

DOE, 1993. *Technology Name: Fixed Hearth Plasma Torch Process,* Technology Information Profile (Rev. 2) for ProTech, DOE ProTech Database, TTP Reference No.: PE-021202.

EPA, 1992. *Babcock and Wilcox—Cyclone Furnace Vitrification*, EPA RREL, series includes Technology Evaluation Vol. I, EPA/540/R-92/017A, PB92-222215; Technology Evaluation Vol. II, EPA/540/R-92/017B, PB92-222223; Applications Analysis, EPA/540/AR-92/017, PB93-122315; Technology Demonstration Summary, EPA/540/SR-92/017; and Demonstration Bulletin, EPA/540/MR-92/011.

EPA, 1993. *Babcock and Wilcox—Cyclone Furnace Vitrification*, EPA RREL, Emerging Tech., Bulletin, EPA/540/P-92/010; Emerging Tech. Report, EPA/540/R-93/507, PB93-163038; Emerging Tech. Summary, EPA/540/SR-93/507.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
DOE Butte, MT	Laurel Staley EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7863 Fax: (513) 569-7620	Heavy metal waste fed into plasma arc centrifugal treatment unit.	28,000 ppm zinc oxide 1,000 ppm hexachloro-benzene	Meets TCLP	$2,000/metric ton ($1,816/ton)
Babcock & Wilcox, Alliance Research Center Alliance, OH	Laurel Staley EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7863 Fax: (513) 569-7620	Wastes containing heavy metals and organic compounds fed into a cyclone furnace. Pilot scale.	TCLP 49.9 ppm Cd 2.67 ppm Cr 97.1 ppm Pb	TCLP <0.12 ppm Cd 0.22 ppm Cr <0.31 ppm Pb >99.99% DRE for anthracene and dimethylphthalate	$495 to $605/ton ($450 to $550/ton)
HRD Facility Monaca, PA	Marta Richards EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268	Wastes containing heavy metals and organic compounds fed into a hot reducing atmosphere.	54,000 ppm Pb 410 ppm Cd 5,200 ppm As 860 ppm Ba 88 ppm Cr	TCLP 0.474 ppm As 0.175 ppm Ba <0.05 ppm Cd <0.06 ppm Cr <0.33 ppm Pb	$220 to $1,020/metric ton ($200 to $930/ton)

Points of Contact:

Contact	Government Agency	Phone	Location
Jaffer Mohiuddin	DOE	(301) 903-7965	EM-552, Trevion II Washington, DC 20585
Randy Parker	EPA RREL	(513) 569-7271 Fax: (513) 569-7620	26 West M.L. King Dr. Cincinnati, OH 45268
Hany H. Zaghloul, P.E.	USACE CERL	(217) 373-7249 (217) 352-6511 (800) USA-CERL	P.O. Box 9005 Champaign, IL 618269005
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.28 EXCAVATION, RETRIEVAL, AND OFF-SITE DISPOSAL

Description: Contaminated material is removed and transported to permitted off-site treatment and/or disposal facilities. Some pretreatment of the contaminated media usually is required in order to meet land disposal restrictions.

4-28 TYPICAL CONTAMINATED SOIL EXCAVATION DIAGRAM

Applicability: Excavation and off-site disposal is applicable to the complete range of contaminant groups with no particular target group. Although excavation and off-site disposal alleviates the contaminant problem at the site, it does not treat the contaminants.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Generation of fugitive emissions may be a problem during operations.
- The distance from the contaminated site to the nearest disposal facility will affect cost.
- Depth and composition of the media requiring excavation must be considered.
- Transportation of the soil through populated areas may affect community acceptability.
- Disposal options for certain waste (e.g., mixed waste or transuranic waste) may be limited. There is currently only one licensed disposal facility for radioactive and mixed waste in the United States.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge).

The type of contaminant and its concentration will impact off-site disposal requirements. Soil characterization as dictated by land disposal restrictions (LDRs) are required. Most hazardous wastes must be treated to meet either RCRA or non-RCRA treatment standards prior to land disposal. Radioactive wastes would have to meet disposal facility waste form requirements based on waste classification.

Performance Data: Excavation and off-site disposal is a well proven and readily implementable technology. Prior to 1984, excavation and off-site disposal was the most common method for cleaning up hazardous waste sites. Excavation is the initial component in all ex situ treatments. As a consequence, the remediation consulting community is very familiar with this option.

The excavation of 18,200 metric tons (20,000 tons) of contaminated soil would require about 2 months. Disposal of the contaminated media is dependent upon the availability of adequate containers to transport the hazardous waste to a RCRA-permitted facility.

CERCLA includes a statutory preference for treatment of contaminants, and excavation and off-site disposal is now less acceptable than in the past. The disposal of hazardous wastes is governed by RCRA (40 CFR Parts 261-265), and the U.S. Department of Transportation (DOT) regulates the transport of hazardous materials (49 CFR Parts 172-179, 49 CFR Part 1387, and DOT-E 8876).

DOE has demonstrated a cryogenic retrieval of buried waste system, which uses liquid nitrogen (LN_2) to freeze soil and buried waste to reduce the spread of contamination while the buried material is retrieved with a series of remotely operated tools. Other excavation/retrieval systems that DOE is currently developing include a remote excavation system, a hydraulic impact end effector, and a high pressure waterjet dislodging and conveyance end effector using confined sluicing.

Cost: Cost estimates for excavation and disposal range from $300 to $510 per metric ton ($270 to $460 per ton) depending on the nature of hazardous materials and methods of excavation. These estimates include excavation/removal, transportation, and disposal at a RCRA permitted facility. Excavation and off-site disposal is a relatively simple process, with proven procedures. It is a labor-intensive practice with little potential for further automation. Additional costs may include soil characterization and treatment to meet land ban requirements.

References:

Church, H.K., 1981. *Excavation Handbook,* McGraw Hill Book Co., New York, NY.

EPA, 1991. *Survey of Materials-Handling Technologies Used at Hazardous Waste Sites,* EPA, ORD, Washington, DC, EPA/540/2-91/010.

EPA, 1992. *McColl Superfund Site — Demonstration of a Trial Excavation,* EPA RREL, series include Technology Evaluation EPA/S40/R-92/015, PB92-226448; Applications Analysis, EPA/540/AR-92/015; and Technology Demonstration. Summary, EPA/540/SR/-92/015.

Points of Contact:

Contact	Government Agency	Phone	Location
Jaffer Mohiuddin	DOE Program Manager	(301) 903-7965	EM-552, Trevion II Washington, DC 20585
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.29 NATURAL ATTENUATION

Description: For natural attenuation, natural subsurface processes—such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials—are allowed to reduce contaminant concentrations to acceptable levels. Natural attenuation is not a "technology" per se, and there is significant debate among technical experts about its use at hazardous waste sites. Consideration of this option requires modeling and evaluation of contaminant degradation rates and pathways. The primary objective of site modeling is to demonstrate that natural processes of contaminant degradation will reduce contaminant concentrations below regulatory standards before potential exposure pathways are completed. In addition, sampling and sample analysis must be conducted throughout the process to confirm that degradation is proceeding at rates consistent with meeting cleanup objectives.

4-29 TYPICAL MONITORING WELL CONSTRUCTION DIAGRAM

Natural attenuation is not the same as "no action," although it often is perceived as such. CERCLA requires evaluation of a "no action" alternative but does not require evaluation of natural attenuation. Natural attenuation is considered in the Superfund program on a case-by-case basis, and guidance on its use is still evolving. It has been selected at Superfund sites where, for example, PCBs are strongly sorbed to deep subsurface soils and are not migrating; where removal of DNAPLs has been determined to be technically impracticable [Superfund is developing technical impracticability (TI) guidance]; and where it has been determined that active remedial measures would be unable to significantly speed remediation time frames. Where contaminants are expected to remain in place over long periods of time, as in the first two examples, TI waivers must be obtained. In all cases, extensive site characterization is required.

The attitude toward natural attenuation varies among agencies. USAF carefully evaluates the potential for use of natural attenuation at its sites; however, EPA accepts its use only in certain special cases.

Applicability: Target contaminants for natural attenuation are nonhalogenated VOCs, SVOCs, and fuel hydrocarbons. Halogenated VOCs and SVOCs and pesticides may be less responsive to natural attenuation.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Data must be collected to determine model input parameters.
- Although commercial services for evaluating natural attenuation are widely available, the quality of these services varies widely among the many potential suppliers. Highly skilled modelers are required.
- Intermediate degradation products may be more mobile and more toxic than the original contaminant.
- Natural attenuation should be used only where there are no impacts on potential receptors.
- Contaminants may migrate before they are degraded.
- The site may have to be fenced and may not be available for re-use until contaminant levels are reduced.
- If source material exists, it may have to be removed.
- Some inorganics can be immobilized, such as mercury, but they will not be degraded.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge).

Many potential suppliers can perform the modeling, sampling, and sample analysis required for justifying and monitoring natural attenuation. The extent of contaminant degradation depends on a variety of parameters, such as contaminant types and concentrations, temperature, moisture, and availability of nutrients/electron acceptors (e.g., oxygen and nitrate).

When available, information to be obtained during data review includes:

- Soil and groundwater quality data:
  - Three-dimensional distribution of residual-, free-, and dissolved-phase contaminants. The distribution of residual- and free-phase contaminants will be used to define the dissolved-phase plume source area.
  - Groundwater and soil geochemical data.
  - Chemical and physical characteristics of the contaminants.
  - Potential for biodegradation of the contaminants.
- Geologic and hydrogeologic data:
  - Lithology and stratigraphic relationships.
  - Grain-size distribution (sand vs. silt vs. clay).
  - Flow gradient.
  - Preferential flow paths.
  - Interaction between groundwater and surface water.
  - Location of potential receptors: groundwater, wells, and surface water discharge points.

Performance Data: Natural attenuation has been selected by AFCEE for remediation at 45 USAF sites.

Cost: There are costs for modeling contamination degradation rates to determine whether natural attenuation is a feasible remedial alternative. Additional costs are for subsurface sampling and sample analysis (potentially extensive) to determine the extent of contamination and confirm contaminant degradation rates and cleanup status. Skilled labor hours are required to conduct the modeling, sampling, and analysis. O&M costs would be required for monitoring to confirm that contaminant migration has not occurred.

References:

Scovazzo, P.E., D. Good, and D.S. Jackson, 1992. "Soil Attenuation: In Situ Remediation of Inorganics," in *Proceedings of the HMC/Superfund 1992*, HMCRI, Greenbelt, MD.

Bailey, G.W., and J.L. White, 1970. "Factors Influencing the Adsorption, Desorption, and Movement of Pesticides in Soil," in *Residue Reviews*, F.A. Gunther and J.D. Gunther, Editors, Springer Verlag, pp. 29-92.

Hassett, J.J., J.C. Means, W.L. Banwart, and S.G. Woods, 1980. *Sorption Properties of Sediments and Energy-Related Pollutants*, EPA, Washington, DC, EPA/600/3-80-041.

Hassett, J.J., W.L. Banwart, and R.A. Griffin, 1983. "Correlations of Compound Properties with Sorption Characteristics of Nonpolar Compounds by Soils and Sediments; Concepts and Limitations," *Environment and Solid Wastes*, pp. 161-178, C.W. Francis and S.I. Auerbach, Editors, Butterworths, Boston, MA.

Jeng, C.Y., D.H. Chen, and C.L. Yaws, 1992. "Data Compilation for Soil Sorption Coefficient," *Pollution Engineering*, 15 June 1992.

Miller, R.N. 1990. "A Field-Scale Investigation of Enhanced Petroleum Hydrocarbon Biodegradation in the Vadose Zone at Tyndall Air Force Base, Florida," in *Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Groundwater*, pp. 339-351, Prevention, Detection, and Restoration Conference: NWAA/API.

Wiedemeier, T.H., D.C. Downey, J.T. Wilson, D.H. Kampbell, R.N. Miller, and J.E. Hansen. 1994. *Technical Protocol for Implementing the Intrinsic Remediation (Natural Attenuation) with Long-Term Monitoring Option for Dissolved-Phase Fuel Contamination in Ground Water*, Brooks Air Force Base, San Antonio, TX.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Hill AFB, UT	AFCEE/ERT Jerry Hansen (210) 536-4353 Fax: (210) 536-4339	NA	NA	NA	NA
Eglin AFB, FL	AFCEE/ERT Jerry Hansen (210) 536-4353 Fax: (210) 536-4339	NA	NA	NA	NA
Elmendorf AFB, AL	AFCEE/ERT Jerry Hansen (210) 536-4353 Fax: (210) 536-4339	NA	NA	NA	NA

Note: NA = Not available.

Points of Contact:

Contact	Government Agency	Phone	Location
Capt. Tom Venoge	USAF	(904) 283-6205	AL-EQW Tyndall AFB, FL 32403
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.30 CO-METABOLIC PROCESSES

Description: Co-metabolism is one form of secondary substrate transformation in which enzymes produced for primary substrate oxidation are capable of degrading the secondary substrate fortuitously, even though the secondary substrates do not afford sufficient energy to sustain the microbial population. An emerging application involves the injection of water containing dissolved methane and oxygen into groundwater to enhance methanotrophic biological degradation. This class of microorganisms can degrade chlorinated solvents, such as vinyl chloride and TCE, by co-metabolism.

4-30 TYPICAL CO-METABOLIC BIOREMEDIATION SYSTEM (IN SITU) FOR CONTAMINATED GROUNDWATER

Applicability: Target contaminants for co-metabolic processes are VOCs and SVOCs. The process may also have some effectiveness in treating fuels and pesticides. As with other biological treatments, treatability is highly dependent upon the biodegradability of the contaminants.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- This technology is still under development.
- Where the subsurface is heterogeneous, it is very difficult to circulate the methane solution throughout every portion of the contaminated zone. Higher permeability zones are cleaned up much faster because groundwater flow rates are greater.

- Safety precautions (such as removing all ignition sources in the area) must be used when handling methane.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Characteristics that should be addressed prior to system design include aquifer permeability, site hydrology, dissolved oxygen content, pH, and depth, type, concentration, and biodegradability of contaminants.

Performance Data: While ex situ bioreactors for methanotrophic TCE biodegradation are being used in full-scale remediation, in situ application has not yet been demonstrated at a practical scale. A field demonstration project has been conducted at DOD's Moffett Naval Air Station, and another is being conducted at DOE's Savannah River site.

The DOE pilot-scale demonstration was performed at the Savannah River site's abandoned seepage basin and process sewer line employed for disposal of solvents used to degrease nuclear fuel target elements. Contamination is mostly TCE and PCE with concentrations of 10,000 ppb in soil and 1,000 ppb in groundwater. Extensive soil and groundwater monitoring has demonstrated that when methanotroph densities increased five orders of magnitude, TCE and PCE concentrations declined to less than 2 ppb.

Cost: For the DOE Savannah River demonstration, capital investment costs were $150K and 200 manhours for site preparation, setup, and assembly. The operation is low maintenance, requiring only one technician at 25% time (10 hours per week); other operational costs are for electricity, natural gas, and equipment maintenance.

O&M costs can be significant because a continuous source of methane solution must be delivered to the contaminated groundwater.

References:

EPA, 1993. *In Situ Bioremediation: Biodegradation of Trichloroethylene and Tetrachloroethylene by Injection of Air and Methane,* Innovative Remedial Technology Information Request Guide.

DOE, 1991. "Modeling Bioremediation Experiments at SRS ID," *FY92 Technical Task Description*, TTP No. AL 1211-02.

DOE, 1992. "SRS Integrated Demo: Remediation Tasks," *FY92 Technical Task Description*, TTP Reference Number: SR 1211-06.

DOE-SR, 1993. *Technical Name: Methanotrophic In Situ Bioremediation Using Methane/Air and Gaseous Nutrient Injection Via Horizontal Wells*,

Technology Information Profile, Rev. 2, DOE ProTech Database, TTP Reference Number: SR-1211-06.

DOE, 1991. "VOCs in Non-Arid Soils Integration Demonstration, Analysis, and Evaluation Task," *FY92 Technical Task Summary/Description*, TTP Reference Number: SF 2111-01.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Tinker AFB and ORNL	Alison Thomas AL/EQW-OL 139 Barnes Drive Tyndall AFB, FL 32403 (904) 283-6303	Ex situ methanotrophic bioreactor	NA	NA	NA
DOE Savannah River Site Aiken, SC	Terry C. Hazen Westinghouse Savannah River Co. P.O. Box 616 Bldg. 773-42A Aiken, SC 29802 (803) 725-5178	Methane and air injected into seepage basin by horizontal wells	NA	TCE/PCE <2 ppb	$150K cap
Bendix Corp./Allied Automotive St. Joseph, MI	NA	CERCLA Lead Predesign-anaerobic cycle to treat TCE	TCE, DCE, DCA, VC	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Ronald Lewis	EPA RREL	(513) 569-7856 Fax: (513) 569-7620	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401
Kurt Gerdes	DOE	(301) 903-7289	EM-551, Trevion II Washington, DC 20585

4.31 NITRATE ENHANCEMENT

Description: Solubilized nitrate is circulated throughout groundwater contamination zones to provide electron acceptors for biological activity and enhance the rate of degradation of organic contaminants by naturally occurring microbes. Development of nitrate enhancement is still at the pilot scale.

4-31 TYPICAL NITRATE-ENHANCED BIOREMEDIATION SYSTEM

This technology enhances the anaerobic biodegradation through the addition of nitrate. Fuel has been shown to degrade rapidly under aerobic conditions, but success often is limited by the inability to provide sufficient oxygen to the contaminated zones as a result of the low water solubility of oxygen. Nitrate also can serve as an electron receptor and is more soluble in water than oxygen. The addition of nitrate to an aquifer results in the anaerobic biodegradation of toluene, ethylbenzene, and xylenes (TEX). The benzene component of fuel has been found to be recalcitrant under strictly anaerobic conditions. A mixed oxygen/nitrate system would prove advantageous in that the addition of nitrate would supplement the demand for oxygen rather than replace it, allowing for benzene to be biodegraded under microaerophilic conditions.

Applicability: Target contaminants for the process are nonhalogenated VOCs, SVOCs, and fuels. Nitrate enhancement has primarily been used to remediate groundwater

contaminated by BTEX. Pesticides also should have limited treatability. As with other biological treatments, this is highly dependent upon the biodegradability of the contaminants.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- This technology has been found to be effective on only a narrow spectrum of contaminants to date.
- Where the subsurface is heterogeneous, it is very difficult to circulate the nitrate solution throughout every portion of the contaminated zone. Higher permeability zones will be cleaned up much faster because groundwater flow rates are greater.
- Nitrate has a maximum contaminant level (MCL) of 10 mg/L. The location and concentration of nitrate addition would have to consider this, and downgradient monitoring may be required.
- Many states prohibit nitrate injection into groundwater because nitrate is regulated through drinking water standards.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Characteristics that should be investigated prior to system design include aquifer permeability, site hydrology, dissolved oxygen content, pH, and depth, type, concentration, and biodegradability of contaminants.

Performance Data: As with other in situ biodegradation processes, the success of this technology is highly dependent upon soil and chemical properties.

Cost: One cost estimate is in the range of $40 to $60 per liter ($160 to $230 per gallon) of residual fuel removed from the aquifer.

References:

Hutchins, S.R., G.W. Sewell, D.A. Kovacs, and G.A. Smith, 1991. "Biodegradation of Aromatic Hydrocarbons by Aquifer Microorganisms Under Denitrifying Conditions," *Environmental Science and Technology*,No. 25, pp. 68-76.

U.S. Department of Commerce, National Technical Information Service (NTIS), May 1991. *Nitrate for Biorestoration of an Aquifer Contaminated with Jet Fuel.*

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Eglin AFB, FL	Alison Thomas AL/EQW Tyndall AFB (904) 283-6303	Nitrate enhancement of anaerobic degradation of JP-4	NA	NA	NA
Hanahan Defense Supply Point, SC	Don A. Vroblesky USGS Columbia, SC 29210-7651 (803) 750-6115	Nitrates added to groundwater and injected into aquifer to enhance natural biodegradation of jet fuel	2,000 mg/L BTEX	<10 mg/L BTEX	NA
Stalworth Timber Beatrice, AL	Jason Darby (404) 347-3433	RCRA Lead — Currently in predesign — addition of O_2 potassium nitrate, potassium phosphate, and molasses	NA	NA	NA
Park City Park City, KS	John Wilson (405) 332-8800	CERCLA Lead — Full scale since December 1992. Ammonium chloride and nitrate addition	Petro, benzene	Benzene, 5 ppb	$650K expected total

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Alison Thomas	USAF	(904) 283-6303	AL/EQW-OL 139 Barnes Drive Tyndall AFB, FL 32403
Frank Chapelle	USGS	(803) 750-6116	720 Gracern Road, Stephenson Center, Suite 129 Columbia, SC 29210
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.32 OXYGEN ENHANCEMENT WITH AIR SPARGING

Description: Air is injected under pressure below the water table to increase groundwater oxygen concentrations and enhance the rate of biological degradation of organic contaminants by naturally occurring microbes. (VOC stripping enhanced by air sparging is addressed in Treatment Technology Profile 4.34). Air sparging increases mixing in the saturated zone, which increases the contact between groundwater and soil. The ease and low cost of installing small-diameter air injection points allows considerable flexibility in the design and construction of a remediation system. Oxygen enhancement with air sparging is typically used in conjunction with SVE or bioventing to enhance removal of the volatile component under consideration.

4-32 TYPICAL OXYGEN-ENHANCED BIOREMEDIATION SYSTEM FOR CONTAMINATED GROUNDWATER WITH AIR SPARGING

Applicability: Oxygen enhancement with air sparging is primarily designed to treat nonhalogenated VOCs, SVOCs, and fuels. The process has limited effectiveness on some pesticides.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Fracturing of the product plume is a primary concern and has led to some agencies not allowing the use of air sparging where free product

is present. This technology may be used in conjunction with free product recovery.

- A permeability differential, such as a clay layer, above the air injection zone can reduce the effectiveness of air sparging.

- Where vertical air flow is restricted as a result of the presence of less permeable strata, sparging can push contaminated groundwater away from the injection point. In these cases, a groundwater recovery system or SVE system may be needed.

- Vapors may rise through the vadose zone and be released into the atmosphere.

- Because air sparging increases pressure in the vadose zone, vapors can build up in building basements, which are generally low pressure areas.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Characteristics that should be investigated prior to system design include aquifer permeability, site hydrology, dissolved oxygen content, pH, and depth, type, concentration, and biodegradability of contaminants.

Performance Data: As with other biological treatments, the success of this technology is highly dependent upon the biodegradability of the contaminants.

Although oxygen enhancement with air sparging is relatively new, the related technology, bioventing (Treatment Technology Profile 4.2), is rapidly receiving increased attention from remediation consultants. This technology employs the same concepts as bioventing, except that air is injected below the water table to promote the remediation of groundwater.

Cost: Cost estimates are $10 to $20 per 1,000 liters ($50 to $100 per 1,000 gallons) of groundwater treated or $85,000 per site.

References:

Dey, C.D., R.A. Brown, and W.E. McFarland, 1991. "Integrated Site Remediation Combining Groundwater Treatment, Soil Vapor Recovery, and Bioremediation," *Hazardous Materials Control*, Vol. 4, No. 2, pp. 32-39, March/April 1991.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Mayville Fire Department Mayville, MI	Jon Mayes (517) 684-9141	Groundwater treatment with indigenous organisms	BTEX (1/800/70/300 ppb)	Expected 1/94	NA
Dover AFB Dover, DE	Milton Beck (302) 677-6845	Air sparge with bioventing pilot studies	Several areas: PAHs, TCE metals, solvents	BTEX 10 ppm TPH 1,000 ppm	One area (230,000 m^3) Total expected full scale $1.2M
French Limited Crosby, TX	Judith Black (214) 655-6735	CERCLA Lead — air sparge, O_2, and nutrient addition	PCB, As, and petroleum	MCLs	Total expected $90M

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Jeffrey M. Fischer	DOE - USGS	(609) 771-3900	Mountain View Office Park 810 Bear Tavern Road Suite 206 West Trenton, NJ 08628
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.33 OXYGEN ENHANCEMENT WITH HYDROGEN PEROXIDE

Description: A dilute solution of hydrogen peroxide is circulated through the contaminated groundwater zone to increase the oxygen content of groundwater and enhance the rate of aerobic biodegradation of organic contaminants by naturally occurring microbes.

4-33 OXYGEN-ENHANCED (H_2O_2) BIOREMEDIATION SYSTEM

Applicability: Oxygen enhancement with hydrogen peroxide is primarily designed to treat VOCs, SVOCs, and fuels. The process may have some effect in treating some pesticides.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Concentrations of H_2O_2 greater than 100 to 200 ppm in groundwater are inhibiting to microorganisms.
- A groundwater circulation system must be created so that contaminants do not escape from zones of active biodegradation.
- Where the subsurface is heterogeneous, it is very difficult to circulate the hydrogen peroxide solution throughout the different zones of contamination. Higher permeability zones are cleaned up much faster because groundwater flow rates are greater.

- Microbial enzymes and high iron content of subsurface materials can rapidly reduce concentrations of hydrogen peroxide and reduce zones of influence.

- Amended hydrogen peroxide can be consumed very rapidly near the injection well, which creates two significant problems: biological growth can be limited to the region near the injection well, limiting adequate contamination/microorganism contact throughout the contaminated zone; and biofouling of wells can retard the input of nutrients.

- A surface treatment system, such as air stripping or carbon adsorption, may be required to treat extracted groundwater prior to re-injection or disposal.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate). For best results, factors that must be considered include redox conditions, presence of nutrient trace elements, pH, temperature, permeability of the subsurface materials, and the contaminants' biodegradability.

Performance Data: Two previous in situ bioremediation field tests that used hydrogen peroxide to enhance the aerobic degradation of jet fuel showed poor oxygen transfer and use and aquifer plugging as a result of geochemical reactions resulting in poor overall performance of this technology. A joint effort is underway by USAF and EPA's Robert S. Kerr Environmental Research Laboratory (RSKERL) to perform an enhanced anaerobic field demonstration at a petroleum, oils, and lubricant (POL) contamination site at Eglin AFB in Florida. Field work for this effort began in March 1993 with site characterization activities and sample collection for laboratory treatability tests. Construction of the treatment system was scheduled to begin in January 1994, and operation will continue for about 9 months.

Cost: Typical costs are $10 to $20 per 1,000 liters ($50 to $100 per 1,000 gallons) of groundwater treated. O&M costs can be significant because a continuous source of hydrogen peroxide must be delivered to the contaminated groundwater.

References: Not available.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Knispel Construction Site Horseheads, NJ	Frank Peduto (518) 457-2462	UST Lead — Soil and groundwater in situ land treatment — H_2O_2 and nutrient addition Full-scale remedy January-October 1989	NA	5 ppb petroleum hydro-carbons	O&M $250K
Orkin Facility Fort Pierce, FL	Joe Malinowski (404) 888-2895	TSCA Lead — Planned land treatment of soil/groundwater with H_2O_2 and nutrient addition — aerobic and anaerobic cycles	Chlordane and heptachlor	NA	NA
Farfield Coal & Gas Farfield, IA	Steve Jones (913) 551-7755	CERCLA Lead — Pilot scale H_2O_2 and nitrate injection — possible problem with poor transmissivity of aquifer in full scale	Coal tar BTEX, PAHs	1 ppb benzene, 200 ppt cPAHs	Total expected $1.6M

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.34 AIR SPARGING

Description: Air sparging is an in situ technology in which air is bubbled through a contaminated aquifer. Air bubbles traverse horizontally and vertically through the soil column, creating an underground stripper that removes contaminants by volatilization. These air bubbles carry the contaminants to a vapor extraction system. Vapor extraction is implemented in conjunction with air sparging to remove the generated vapor phase contamination. This technology is designed to operate at high flow rates to maintain increased contact between groundwater and soil and strip more groundwater by sparging.

4-34 TYPICAL AIR SPARGING SYSTEM

Applicability: The target contaminant groups for air sparging are VOCs and fuels. Only limited information is available on the process.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Depth of contaminants and specific site geology must be considered.
- Air injection wells must be designed for site-specific conditions.
- Air flow through the saturated zone may not be uniform.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate). Characteristics that should be determined include vadose zone gas permeability, groundwater flow rate, aquifer permeability, presence of low permeability layers, presence of DNAPLs, depth of contamination, and contaminant volatility and solubility.

Performance Data: This technology will be demonstrated over the next 2 to 3 years at DOE's Hanford Reservation as part of the agency's Integrated Technology Demonstration Program for Arid Sites. Air sparging has demonstrated sensitivity to minute permeability changes, which can result in localized stripping between the sparge and monitoring wells.

Cost: One estimate, $371,000 to $865,000 per hectare ($150,000 to $350,000 per acre) of groundwater plume to be treated, was available.

References: Hildebrandt, W. and F. Jasiulewicz, 1992. "Cleaning Up Military Bases," *The Military Engineer*, No. 55, p. 7, September-October 1992.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Savannah River, IL	NA	NA	PCE 3-124 TCE 10-1,031	<184 ppb <1.8 ppb	NA
Conservancy Site Belen, NM	NA	NA	BTX	49-60% reduction	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Steve Stein	Environmental Management Organization, Pacific Northwest Division	(206) 528-3340	4000 N.E. 41st Street Seattle, WA 98105
Steven M. Gorelick	Stanford University Dept. of Applied Earth Sciences	(415) 725-2950	Stanford, CA 94305-2225
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.35 DIRECTIONAL WELLS

Description: Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling. Directional well technology is used exclusively as an enhancement technology for other in situ treatment technologies. Technologies used with directional wells include biodegradation, bioventing, SVE, soil flushing, and air sparging.

4-35 TYPICAL DIAGRAM OF IN SITU AIR STRIPPING WITH HORIZONTAL WELLS

Hardware used for directional boring includes wireline coring rigs, hydraulic thrust systems, electric cone penetrometers, steering tracking hardware, sonic drilling, and push coring systems. Hydraulically activated thrust equipment capable of exerting more than 40 tons of thrust is used to push the directional boring heads into the earth. Directional control is obtained by proper positioning of the face of the nonsymmetric boring head. Slow rotation of the boring head will cut and compact the geologic material into the borehole wall. Thrusting a boring head that is not rotating will cause a directional change. The machinery is capable of initiating a borehole, steering down to a desired horizontal depth, continuing at that depth, and then steering back to the surface at a downrange location.

Applicability: Directional well technology is applicable to the complete range of contaminant groups with no particular target group. It is particularly useful when existing structures interfere with placement of vertical wells.

Limitations: The following factors may limit the applicability and effectiveness of this technology:

- Well failures are possible during system installation.
- The potential exists for the wells to collapse.
- Specialized equipment is required.
- Wells are difficult to position precisely.
- Installation of horizontal wells is typically costly.
- Currently, the technology is limited to depths of less than 50 feet.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Performance Data: Testing was performed as part of the Mixed Waste Landfill Integrated Demonstration at Sandia National Laboratories, Albuquerque, NM. Several directional holes were drilled; a depth of 12 meters (40 feet) was achieved with a maximum horizontal extent of 174 meters (570 feet).

A DOE field demonstration at the Savannah River site was performed in FY90 for in situ air stripping (ISAS), a mass transfer process that uses horizontal injection and vacuum extraction wells to remediate sites contaminated with VOCs within the vadose zone and soil/groundwater in the saturated zone. Air is injected into the saturated zone through horizontal injection wells placed below the water table. As the air passes through the contaminant plume, it volatilizes the chemical constituents. This process performs best in homogeneous soil conditions, while heterogeneities such as formations, fractures, clay layers, and partial clay lenses hinder performance. Clay layers often have high contaminant concentrations, while stratigraphy can cause preferential flow paths and limit the process efficiency. ISAS has been shown to be effective when some interbedded, thin, and/or discontinuous clays are present. A full-scale demonstration, including 4% methane enhancement as a bioremediation nutrient in the injection well, was conducted during FY92, with results to be available in FY93. Better underground transport modeling and bioremediation modeling are needed. The technology was also used successfully in the DOE VOCs in the Non-Arid Soils Integrated Demonstration in Savannah River, South Carolina. Testing of directional boring for monitoring equipment installation was performed in an actual contamination zone during the summer of 1992.

Cost: Estimated costs are about $60 to $250 per meter ($20 to $75 per foot) for hydraulic bi-directional thrust drilling. Sonic drilling can be as much as $330 per meter ($100 per foot).

References:

DOE, 1991. "Horizontal Hybrid Directional Boring," *FY92 Technical Task Plan,* TTP Reference No.: AL-ZU23-J2.

DOE, 1991. "SRS Integrated Demonstration: Directional Drilling," *FY92 Technical Task Plan,* TTP Reference No.: SR-1211-01.

DOE, 1992. "Directional Sonic Drilling," *FY93 Technical Task Plan,* TTP Reference No.: AL-2311-05.

DOE, 1993. *Directional Boring and Thrusting with Hybrid Underground Utility Industry Equipment,* ProTech Database, TTP References: AL2211-16 and AL2211-03.

DOE, 1993. *Technology Name: Slant-Angle Sonic Drilling,* Technology Information Profile (Rev. 2), DOE ProTech Database, TTP Reference No.: AL2310-05.

Points of Contact:

Contact	Government Agency	Phone	Location
Skip Chamberlain	DOE-OTD	(301) 903-7248	EM-551, Trevion II Washington, DC 20585
Geoscience Research Drilling Office	DOE-Sandia National Laboratories	(505) 844-2230	P.O. Box 5800 Org. 6111 Albuquerque, NM 87185
Mike Breazeale	USAF	(602) 988-6487	Williams AFB CA/OLS 6001 South Power Road, Bldg. 1 Mesa, AZ 85206-0901
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.36 DUAL PHASE EXTRACTION

Description: A high vacuum system is applied to simultaneously remove liquid and gas from low permeability or heterogeneous formations. The vacuum extraction well includes a screened section in the zone of contaminated soils and groundwater. As the vacuum is applied to the well, soil vapor is extracted, and groundwater is entrained by the extracted vapors. Once above grade, the extracted vapors and groundwater are separated and treated. Dual phase extraction is a full-scale technology.

Dual phase extraction is generally combined with bioremediation, air sparging, or bioventing when the target contaminants include long-chained hydrocarbons. Use of dual phase extraction with these technologies can shorten the cleanup time at a site. It also can be used with pump-and-treat technologies to recover groundwater from high yielding aquifers. Dual phase provides a better control of the groundwater. When containment of vapors/liquids is necessary, the results are far better than those obtained through air sparging.

4-36 TYPICAL DUAL PHASE EXTRACTION SCHEMATIC

Applicability: The target contaminant groups for dual phase extraction are VOCs and fuels. Dual phase vacuum extraction is used to remediate soil and groundwater. It is more effective than SVE for heterogeneous clays and fine sands.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- Site geology and contaminant characteristics/distribution may limit effectiveness.
- Combination with complementary technologies (e.g., pump-and-treat)

may be required to recover groundwater from high yielding aquifers.

- Dual phase extraction requires both water treatment and vapor treatment.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Data needs include contaminant characteristics and distribution, site geology and hydrogeology, and soil properties.

Performance Data: Not available.

Cost: Estimated cost ranges from $85,000 to $500,000 per site.

References: Not available.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Lockheed Aeronautical Systems Co. Burbank, CA	David Bluestein AWD Technologies, Inc. 49 Stevenson St., Suite 600 San Francisco, CA 94105 (415) 227-0822	AWD AquaDetox/SVE System treating groundwate and soil >3 years.	2.2 ppm TCE; 11 ppm PCE; 6,000 ppm total VOC soil gas.	98-99.99 % removal.	$3.2-5.8M capital; <$1.5M yearly O&M.

Points of Contact:

Contact	Government Agency	Phone	Location
Gordon Evans	EPA RREL	(513) 569-7684 Fax: (513) 569-7620	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.37 FREE PRODUCT RECOVERY

Description: Undissolved liquid-phase organics are removed from subsurface formations, either by active methods (e.g., pumping) or a passive collection system. This process is used primarily in cases where a fuel hydrocarbon lens more than 20 centimeters (8 inches) thick is floating on the water table. The free product is generally drawn up to the surface by a pumping system. Following recovery, it can be disposed of, re-used directly in an operation not requiring high-purity materials, or purified prior to re-use. Systems may be designed to recover only product, mixed product and water, or separate streams of product and water (i.e., dual pump or dual well systems). Free product recovery is a full-scale technology.

4-37 TYPICAL FREE PRODUCT RECOVERY DUAL PUMP SYSTEM

Applicability: The target contaminant groups for free product recovery are SVOCs and fuels.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- Site geology and hydrogeology.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

The potential for accumulation of liquid phase product that is free to move by gravity above the water table is dependent on several factors, including physical and chemical properties of the product released (e.g., viscosity, density, composition, and solubility in water); soil properties (e.g., capillary forces, effective porosity, moisture content, organic content, hydraulic conductivity, and texture); nature of the release (e.g., initial date of occurrence, duration, volume, and rate); geology (e.g., stratigraphy that promotes trapped pockets of free product); hydrogeologic regime (e.g., depth to water table, groundwater flow direction, and gradient); and anticipated product recharge rate.

Performance Data: Once free product is detected, the immediate response should include both removal of the source and recovery of product by the most expedient means. Free product recovery methods will often extract contaminated water with the product. If economically desirable, water and product can be separated by gravity prior to disposal or recycling of the product. As a result of the removal of substantial quantities of water during dual pumping operations, on-site water treatment will normally be required. When treatment of recovered water is required, permits will usually be necessary.

Cost: Because of the number of variances involved, establishing general costs for free product response is difficult. Some representative costs are $500 per month for a single phase extraction (hand bailing) system; $1,200 to $2,000 per month for a single phase extraction (skimming) system; and $2,500 to $4,000 per month for a dual pumping system. These costs illustrate the relative magnitudes of the various recovery options available, which are typically less than other types of remediation.

Key cost factors for the recovery of free product include waste disposal, potential for sale of recovered product for recycling, on-site equipment rental (e.g., pumps, tanks, treatment systems), installation of permanent equipment, and engineering and testing costs.

References:

American Petroleum Institute, 1989. *A Guide to the Assessment and Remediation of Underground Petroleum Releases,* Publication 1628, API, Washington, DC, 81 pp.

EPA, 1988. *Cleanup of Releases from Petroleum USTs: Selected Technologies,* Washington, DC, EPA/530/UST-88/001.

Kram, M.L., 1990. *Measurement of Floating Petroleum Product Thickness and Determination of Hydrostatic Head in Monitoring Wells,* NEESA Energy and Environmental News Information Bulletin No. 1B-107.

Kram, M.L., 1993. *Free Product Recovery: Mobility Limitations and Improved Approaches.* NFESC Information Bulletin No. IB-123.

NEESA, 1992. *Immediate Response to Free Product Discovery.* NEESA Document No. 20.2-051.4.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Navy Gasoline Station Coastal Area	Mark Kram NFESC Code 413	>0.25 ft floating product; dual pumping extraction and thermal vacuum spray aeration and spray aeration vacuum extraction	About 12,000 gallons of gasoline	4,000 gallons recovered by diesel pump	$75,000 plus vapor extraction costs
Navy Fuel Farm	Mike Radecki SOUTHWESTDIV	0.5-2.5 ft free product. Captured in pit and pumped out with skimmers and french drains	NA	NA	$300,000 to date
Privately Owned Gasoline Station Near Urban Drinking Water Source	Connecticut DEP (203) 566-4630	Immediate response recovery wells and air stripping	NA	NA	NA
Various USAF and Navy Sites	USAF Armstrong Lab/EQW Tyndall AFB, FL (904) 283-6208 Ron Hoeppel (805) 982-1655	"Bioslurping" technology demonstrations	NA	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Mark Kram	NFESC	(805) 982-2669	Code 413 Port Hueneme, CA 93043
Mike Radecki	SOUTHWESTDIV	(619) 532-3874	San Diego, CA
Tom Schruben	EPA Office of USTs	(703) 308-8875	Washington, DC
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.38 HOT WATER OR STEAM FLUSHING/STRIPPING

Description: Steam is forced into an aquifer through injection wells to vaporize volatile and semivolatile contaminants. Vaporized components rise to the unsaturated (vadose) zone where they are removed by vacuum extraction and then treated. Hot water or steam-based techniques include Contained Recovery of Oily Waste (CROW®), Steam Injection and Vacuum Extraction (SIVE®), In Situ Steam-Enhanced Extraction (ISEE®), and Steam-Enhanced Recovery Process (SERP®). Hot water or steam flushing/stripping is a pilot-scale technology. In situ biological treatment may follow the displacement and is continued until groundwater contaminants concentrations satisfy statutory requirements.

4-38 CROW? SUBSURFACE DEVELOPMENT PROCESS

The process can be used to remove large portions of oily waste accumulations and to retard downward and lateral migration of organic contaminants. The process is applicable to shallow and deep contaminated areas, and readily available mobile equipment can be used.

Applicability: The target contaminant groups for hot water or steam flushing/stripping are SVOCs and fuels. VOCs also can be treated by this technology, but there are more cost-effective processes for sites contaminated with VOCs.

This technology can be applied at manufactured gas plants, wood-treating sites, petroleum-refining facilities, and other sites with soils containing light

to dense organic liquids, such as coal tars, pentachlorophenol solutions, creosote, and petroleum by-products.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Soil type, geology, and hydrogeology will significantly impact process effectiveness.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Performance Data: Four vendors are promoting hot water or steam flushing/stripping processes. The CROW system appears to be the most developed of the four.

The CROW technology was tested both at the laboratory and pilot-scale under the EPA SITE Emerging Technology Program. The program showed the effectiveness of the hot-water displacement and displayed the benefits from the inclusion of chemicals with the hot water.

Cost: Not available.

References:

EPA, 1990. *Toxic Treatments In Situ Steam/Hot Air Stripping Technology*, Applications Analysis Report, Prepared by Science Applications International Corporation, San Diego, CA, for EPA RREL, Cincinnati, OH.

EPA, 1991. *In Situ Steam Extraction Treatment*, Engineering Bulletin, OERR, Washington, DC, EPA Report EPA/540/2-91/005.

EPA, 1992. *The Superfund Innovative Technology Evaluation Program: Technology Profiles* (Fifth Edition), OSWER, EPA/940/R-92/077.

EPA, 1994. *In-Situ Steam Enhanced Recovery System — Hughes Environmental Systems, Inc.*, Demonstration Bulletin EPA/540/MR-94/510.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Huntington Beach, CA	Paul dePercin EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7797	EPA site demo of SERP completed but results not good, probably because of poor application rather than technology delivery ineffectiveness	45,000 yd^3 of soil (diesel removal fuel, TPH, and TRPH)	20-40%	About $40/$yd^3$
Pennsylvania Power & Light Stroudsburg, PA	Eugene Harris EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7862	EPA SITE demo of CROW, starting on-site November 1994	NA	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
John Mathur	DOE	(301) 903-7922	EM-551, Trevion II Washington, DC 20585
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4.39 HYDROFRACTURING

Description: Hydrofracturing is a pilot-scale technology in which pressurized water is injected to increase the permeability of consolidated material or relatively impermeable unconsolidated material. Fissures created in the process are filled with a porous medium that can facilitate bioremediation and/or improve extraction efficiency. Fractures promote more uniform delivery of treatment fluids and accelerated extraction of mobilized contaminants. Typical applications are linked with soil vapor extraction, in situ bioremediation, and pump-and-treat systems.

4-39 TYPICAL SEQUENCE OF OPERATIONS FOR CREATING HYDRAULIC FRACTURES

The fracturing process begins with the injection of water into a sealed borehole until the pressure of the water exceeds the overburden pressure and a fracture is created. A slurry composed of a coarse-grained sand and guar gum gel is then injected as the fracture grows away from the well. After pumping, the sand grains hold the fracture open while an enzyme additive breaks down the viscous fluid. The thinned fluid is pumped from the fracture, forming a permeable subsurface channel suitable for delivery or recovery of a vapor or liquid.

The hydraulic fracturing process can be used in conjunction with soil vapor extraction technology to enhance recovery. Hydraulically-induced fractures are used to deliver fluids and nutrients for in situ bioremediation applications.

Applicability: Hydrofracturing is applicable to a wide range of contaminant groups with no particular target group.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- The technology should not be used in bedrock susceptible to seismic activity.
- Investigation of possible underground utilities, structures, or trapped free product is required.
- The potential exists to open new pathways leading to the unwanted spread of contaminants (e.g., DNAPLs).
- Pockets of low permeability may still remain after using this technology.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Performance Data: The technology has had widespread use in the petroleum and water-well construction industries but is an innovative method for remediating hazardous waste sites.

Cost: The cost per fracture is estimated to be $1,000 to $1,500, based on creating four to six fractures per day. This cost (including equipment rental, operation, and monitoring) is small compared to the benefits of enhanced remediation and the reduced number of wells needed to complete the remediation. A number of factors affect the estimated costs of creating hydraulic fractures at a site. These factors include physical site conditions such as site accessibility and degree of soil consolidation; degree of soil saturation; and geographical location, which affects availability of services and supplies. The first two factors also affect the effectiveness of hydraulic fracturing.

The costs presented in this analysis are based on conditions found at the Xerox Oak Brook site. A full-scale demonstration was not conducted for this technology. Because operating costs were not independently monitored during the pilot-scale demonstrations at the Xerox Oak Brook and Dayton sites, all costs presented in this section were provided by Xerox and University of Cincinnati Center Hill.

References:

EPA, 1993. *Hydraulic Fracturing of Contaminated Soil,* series includes Demonstration Bulletin, EPA/540/MR-93/505; Technology Evaluation and Applications Analysis Combined, EPA/540/R-93/505; and Technology Demonstration Summary, EPA/540/SR-93/505.

Hubbert, M.K and D.G. Willis, 1957. "Mechanics of Hydraulic Fracturing," *Petroleum Transactions AIME,* Vol. 210, pp. 153 through 168.

Murdoch, L.C., 1990. "A Field Test of Hydraulic Fracturing in Glacial Till," in *Proceedings of the Research Symposium,* Ohio, EPA Report, EPA/600/9-90/006.

Murdoch, L.C., 1993. "Hydraulic Fracturing of Soil During Laboratory Experiments, Part I: Methods and Observations; Part II: Propagation; Part III: Theoretical Analysis, *Geotechnique,* Vol. 43, No. 2, Institution of Civil Engineers, London, pp. 255 to 287.

University of Cincinnati (UC), 1991. *Work Plan for Hydraulic Fracturing at the Xerox Oak Brook Site in Oak Brook, Illinois.*

Wolf, A. and L.C. Murdoch, 1992. *The Effect of Sand-Filled Hydraulic Fractures on Subsurface Air Flow: Summary of SVE Field Tests Conducted at the Center Hill Research Facility,* UC Center Hill Facility, Unpublished Report.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Xerox Facility Oak Brook, IL	NA	SVE of organic solvents. 10 times increase in vapor extraction; 30 times increase in area covered; pore water infiltration decreased.	NA	NA	$950 - 1,425 per fracture
Dayton, OH	NA	In situ bioremediation of BTEX/UST site. 100 times increase in water flow; 75% increase in bioremediation rate.	NA	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Naomi Barkley	EPA RREL	(513) 569-7854 Fax: (513) 569-7620	26 West M.L. King Dr. Cincinnati, OH 45268
L. Murdoch, Director of Research	Dept. Civil and Environmental Engineering University of Cincinnati	(513) 569-7897	5995 Center Hill Road Cincinnati, OH
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.40 PASSIVE TREATMENT WALLS

Description: A permeable reaction wall is installed across the flow path of a contaminant plume, allowing the water portion of the plume to passively move through the wall. These barriers allow the passage of water while prohibiting the movement of contaminants by employing such agents as chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and others.

4-40 TYPICAL PASSIVE TREATMENT WALL (CROSS-SECTION)

The contaminants will either be degraded or retained in a concentrated form by the barrier material. The wall could provide permanent containment for relatively benign residues or provide a decreased volume of the more toxic contaminants for subsequent treatment.

Barrier and post-closure monitoring tests are being conducted by DOE in field-scale demonstration plots and are being designed for actual contaminated sites. The range of materials available for augmenting existing barrier practice is broad. Two types of barriers have been the focus of initial efforts of this program, i.e., permeable reactive barriers and in-place bioreactors.

Applicability: Target contaminant groups for passive treatment walls are VOCs, SVOCs, and inorganics. The technology can be used, but may be less effective, in treating some fuel hydrocarbons.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- Passive treatment walls may lose their reactive capacity, requiring replacement of the reactive medium.
- The system requires consistent control of pH levels. When the pH level within the passive treatment wall rises, it reduces the reaction rate and can inhibit effectiveness of the wall.
- Depth and width of barrier.
- Volume cost of treatment medium.
- Biological activity may limit the permeability of the passive treatment wall.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Data needs include hydraulic gradient; contaminant characteristics (depth, areal extent, type, and concentration); groundwater hydrology; water quality, flow rate, and direction; soil permeability; and buffering capacity.

Performance Data: Data have been developed by USAF, the University of Waterloo, and Environmental Technologies but have received limited dissemination in the technical literature to date. This technology currently is available from only one vendor, Environmental Technologies (Canada).

The technology is not commercially available. Laboratory testing phase occurred at CERL from 1989 to present. Full-scale implementation occurred in Albuquerque, New Mexico, between 1989 and 1992.

DOE evaluation of currently installed systems was scheduled to be completed in early 1994. The first barrier and monitoring systems were installed in 1992 and tracer tests, which would include the effects of seasonal changes in the environment, were scheduled for completion in 1993. Approximately two additional years would be required to test and evaluate each additional barrier system.

Baseline technologies currently being used by DOE include grouts, clay slurries, and cements for pure hydrologic barriers, landfill caps for the biotreatment systems, and monitoring well characterization for water-saturation and contaminants during the post-closure monitoring approaches. These barriers are all subject to cracking.

Cost: Field tests at DOE Los Alamos National Laboratory that were scheduled for completion in early 1994 had an initial capital cost of $1,200,000 and an O&M cost of $670,000 in FY93. Life cycle costs for operational systems have not been estimated but are expected to be 5 to 10 times less than excavation.

References:

DOE, 1993. *Technical Name: Barriers and Post-Closure Monitoring*, Technology Information Profile (Rev. 2), DOE Protech Database, TTP No. AL-1211-25.

Hansen, W., et al., 1992. *Barriers and Post-Closure Monitoring*, Briefing Chart, Los Alamos National Laboratory, Los Alamos, NM, TTP No. AL-1212-25.

Site Information:

Site Name	Contact	Summary	Costs
Hill AFB, UT	Maj. Mark Smith USAF Tyndall AFB, FL (904) 283-6126	"Funnel and Gate" Demonstration	NA
Los Alamos National Laboratory	Ken Bostick Mail Stop J495 Organization EES-15 Los Alamos National Laboratory Los Alamos, NM 87545 (505) 667-3331 Fax: (505) 665-3866	Barriers and post-closure monitoring—completion early 1994	$1.2M cap. $670K O&M in FY93

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Richard Scholze	USACE-CERL	(217) 373-3491 (217) 352-6511 (800) USA-CERL	P.O. Box 9005 Champaign, IL 61826-9005
Skip Chamberlain	DOE	(301) 903-7248	EM-551 Trevion II Washington, DC 20585
Mark Smith	USAF	(904) 283-6126	AL/EQW Tyndall AFB, FL 32403
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.41 SLURRY WALLS

Description: Slurry walls are used to contain contaminated groundwater, divert contaminated groundwater from the drinking water intake, divert uncontaminated groundwater flow, and/or provide a barrier for the groundwater treatment system.

4-41 TYPICAL KEYED-IN SLURRY WALL (CROSS SECTION)

These subsurface barriers consist of a vertically excavated trench that is filled with a slurry. The slurry hydraulically shores the trench to prevent collapse and forms a filter cake to reduce groundwater flow. Slurry walls often are used where the waste mass is too large for treatment and where soluble and mobile constituents pose an imminent threat to a source of drinking water.

Slurry walls are a full-scale technology that have been used for decades as long-term solutions for controlling seepage. They are often used in conjunction with capping. The technology has demonstrated its effectiveness in containing greater than 95% of the uncontaminated groundwater; however, in contaminated groundwater applications, specific contaminant types may degrade the slurry wall components and reduce the long-term effectiveness.

Most slurry walls are constructed of a soil, bentonite, and water mixture;

walls of this composition provide a barrier with low permeability and chemical resistance at low cost. Other wall compositions, such as sheet piling, cement, bentonite, and water, may be used if greater structural strength is required or if chemical incompatibilities between bentonite and site contaminants exist.

Slurry walls are typically placed at depths less than 15 meters (50 feet) and are generally 0.6 to 1.2 meters (2 to 4 feet) in thickness. The most effective application of the slurry wall for site remediation or pollution control is to base (or key) the slurry wall 0.6 to 0.9 meters (2 to 3 feet) into a low permeability layer such as clay or bedrock, as shown in the preceding figure. This "keying-in" provides for an effective foundation with minimum leakage potential. An alternate configuration for slurry wall installation is a "hanging" wall in which the wall projects into the groundwater table to block the movement of lower density or floating contaminants such as oils, fuels, or gases. Hanging walls are used less frequently than keyed-in walls.

Applicability: Slurry walls contain the groundwater itself, thus treating no particular target group of contaminants. They are used to contain contaminated groundwater, divert contaminated groundwater from drinking water intake, divert uncontaminated groundwater flow, and/or provide a barrier for the groundwater treatment system.

Limitations: Factors that may limit the applicability and effectiveness of the process include:

- The technology only contains contaminants within a specific area.
- Soil-bentonite backfills are not able to withstand attack by strong acids, bases, salt solutions, and some organic chemicals. Other slurry mixtures can be developed to resist specific chemicals.
- There is the potential for the slurry walls to degrade or deteriorate over time.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

The following factors, at a minimum, must be assessed prior to designing effective soil-bentonite slurry walls: maximum allowable permeability, anticipated hydraulic gradients, required wall strength, availability and grade of bentonite to be used, boundaries of contamination, compatibility of wastes and contaminants in contact with slurry wall materials, characteristics (i.e., depth, permeability, and continuity) of substrate into which the wall is to be keyed, characteristics of backfill material (e.g., fines content), and site terrain and physical layout.

Performance Data:

Slurry walls have been used for decades, so the equipment and methodology are readily available and well known; however, the process of designing the proper mix of wall materials to contain specific contaminants is less well developed. Excavation and backfilling of the trench is critical and requires experienced contractors.

Cost:

Costs likely to be incurred in the design and installation of a standard soil-bentonite wall in soft to medium soil range from $540 to $750 per square meter ($5 to $7 per square foot) (1991 dollars). These costs do not include variable costs required for chemical analyses, feasibility, or compatibility testing. Testing costs depend heavily on site-specific factors.

Factors that have the most significant impact on the final cost of soil-bentonite slurry wall installation include:

- Type, activity, and distribution of contaminants.
- Depth, length, and width of wall.
- Geological and hydrological characteristics.
- Distance from source of materials and equipment.
- Requirements for wall protection and maintenance.
- Type of slurry and backfill used.
- Other site-specific requirements as identified in the initial site assessment (e.g., presence of contaminants or debris).

References:

Goldberg-Zoino and Associates, Inc., 1987. *Construction Quality Control and Post-Construction Performance for the Gilson Road Hazardous Waste Site Cutoff Wall*, EPA Report EPA/600/2-87/065.

McCandless, R.M. and A. Bodocsi, 1987. *Investigation of Slurry Cutoff Wall Design and Construction Methods for Containing Hazardous Wastes,* EPA Report EPA/600/2-87/063.

Miller, S.P., 1979. *Geotechnical Containment Alternatives for Industrial Waste Basin F, Rocky Mountain Arsenal, Denver, Colorado: A Quantitative Evaluation,* USAE-WES Technical Report GL-79-23.

Spooner, P.A., et al., 1984. *Slurry Trench Construction for Pollution Migration Control,* EPA Report EPA/540/2-84/001.

USACE, 1986. *Civil Works Construction Guide Specification for Soil-Bentonite Slurry Trench Cutoffs,* National Institute of Building Sciences,

Construction Criteria Base, CW-02214.

Zappi, M.E., D.D. Adrian, and R.R. Shafer, 1989. "Compatibility of Soil-Bentonite Slurry Wall Backfill Mixtures with Contaminated Groundwater," in *Proceedings of the 1989 Superfund Conference*,Washington, DC.

Zappi, M.E., R.A. Shafer, and D.D. Adrian, 1990. *Compatibility of Ninth Avenue Superfund Site Ground Water with Two Soil-Bentonite Slurry Wall Backfill Mixtures,* WES Report No. EL-90-9.

Site Information:

Site Name	Contact	Summary	Costs
Hazardous Waste Landfill	GEO-CON, Inc.	Bentonite alternative used because of saltwater environment and presence of incompatible organic compound.	NA
Sanitary Landfill	GEO-CON, Inc.	Limited working area.	NA
Coal Tar Disposal Pond	NA	Circumferential containment of leachate from pond with metals and phenols. Keyed to impervious till.	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Jesse Oldham or Mark E. Zappi	USAE-WES	(601) 634-3111 (601) 634-2856	Attn: CEWES-EE-S 3903 Halls Ferry Road Vicksburg, MS 39180-6199
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.42 VACUUM VAPOR EXTRACTION

Description: In vacuum vapor extraction (also known as in well air stripping), air is injected into a well, lifting contaminated groundwater in the well and allowing additional groundwater flow into the well. Once inside the well, some of the VOCs in the contaminated groundwater are transferred from the water to air bubbles, which rise and are collected at the top of the well by vapor extraction. The partially treated groundwater is never brought to the surface; it is forced into the unsaturated zone, and the process is repeated. As groundwater circulates through the treatment system in situ, contaminant concentrations are gradually reduced. Vacuum vapor extraction is a pilot-scale technology.

4-42 TYPICAL UVB VACUUM VAPOR EXTRACTION DIAGRAM

Applicability: The target contaminant groups for vacuum vapor extraction are halogenated VOCs, SVOCs, and fuels. Variations of the technology may allow for its effectiveness against some nonhalogenated VOCs, SVOCs, pesticides, and inorganics.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- Fouling of the system may occur by oxidized constituents in the

groundwater.

- Shallow aquifers may limit process effectiveness.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Performance Data: A variation of this process, called UVB (Unterdruck-Verdampfer Brunner), has been used at numerous sites in Germany and has been introduced recently into the United States.

Stanford University has developed another variation of this process, an in-well sparging system, which is currently being evaluated as part of DOE's Integrated Technology Demonstration Program. The Stanford system combines air-lift pumping with a vapor stripping technique.

Awareness of this process is limited in the United States but can be expected to increase as development and demonstration of technologies based on the process continue.

Cost: Not available.

References: Not available.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
March AFB, CA	Jeff Bannon WESTON 100 N. First St. Suite 210 Burbank, CA 91502 (818) 556-5226 Fax: (818) 556-6894	Site demo of UVB system	NA	NA	NA
March AFB, CA	Michelle Simon EPA RREL (513) 569-7469	Site demo: air lift pumping, in situ vapor stripping, and air sparging	30 ppb TCE at well inlet	<1 ppb	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Michelle Simon	EPA RREL	(513) 569-7469 Fax: (513) 569-7676	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.43 BIOREACTORS

Description: Bioreactors degrade contaminants in water with microorganisms through attached or suspended biological systems. In suspended growth systems, such as activated sludge, fluidized beds, or sequencing batch reactors, contaminated groundwater is circulated in an aeration basin where a microbial population aerobically degrades organic matter and produces CO_2, H_2O, and new cells. The cells form a sludge, which is settled out in a clarifier, and is either recycled to the aeration basin or disposed of. In attached growth systems, such as upflow fixed film bioreactors, rotating biological contactors (RBCs), and trickling filters, microorganisms are established on an inert support matrix to aerobically degrade water contaminants.

4-43 TYPICAL ROTATING BIOLOGICAL CONTACTOR (RBC)

One promising methodology includes the use of active supports (such as activated carbon, which adsorbs the contaminant and slowly releases it to the microorganisms for degradation). The microbial population may be derived either from the contaminant source or from an inoculum of organisms specific to a contaminant. Other applications include wetland ecosystems and column reactors.

Applicability: Bioreactors are used primarily to treat SVOCs, fuel hydrocarbons, and any biodegradable organic material. The process may be less effective for some pesticides. Successful pilot-scale field studies have been conducted on some halogenated compounds, such as PCP and chlorobenzene and dichloro-benzene isomers.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- Residuals from sludge processes require treatment or disposal.
- Very high contaminant concentrations may be toxic to microorganisms.
- Air pollution controls may need to be applied if there is volatilization from activated sludge processes.
- Low ambient temperatures significantly decrease biodegradation rates, resulting in longer cleanup times or increased costs for heating.
- Nuisance microorganisms may preferentially colonize bioreactors, leading to reduced effectiveness.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Data requirements include contaminants and their concentrations, soil classification, texture, pH, presence of compounds toxic to microorganisms, contaminant biodegradability, flow rate, temperature, and nutrient levels.

Performance Data: This is a well developed technology that has been used for many decades in the treatment of municipal wastewater. Equipment and materials are readily available. As with other pump-and-treat technologies, time needed to clean up is dependent upon subsurface conditions and the rate of desorption of contaminants from subsurface materials, but it is typically faster than in situ bioremediation.

Startup time can be slow if organisms need to be acclimated to the wastes; however, the existence of cultures that have been previously adapted to specific hazardous wastes can decrease startup and detention times.

DOE has demonstrated another biological process, biological destruction of tank waste (BDTW), on the laboratory scale. This process is a separation and volume-reduction process for supernatant and sluiced salt cake waste from underground storage tanks. These wastes are usually composed of various radionuclides and toxic metals concentrated in a nitrate salt solution. The bacteria act as metal and radionuclide adsorbers and also as denitrification catalysts that reproduce themselves at ambient temperature

and pressure. Some degradation of organic contaminants may also occur during the process.

The field demonstration bioreactor tank size is about 100 cubic meters, which corresponds to a waste treatment rate of 2 gpm, sufficient to treat a 1-million gallon tank in 1 year. At the 2-gpm size, the BDTW system is transportable. The current bioreactor is able to process salt solutions having nitrate concentrations up to 300,000 ppm. The maximum salt tolerance is being explored. Power usage is estimated at 20 kW for pumping and agitation.

Cost:

Costs are highly dependent on the contaminants and their concentrations in the influent stream. Biological treatment has often been found to be more economical than carbon adsorption.

Staging will vary from site to site depending on the wastestream. The cost to install a single unit with a protective cover and a surface area of 9,300 to 13,900 square meters (100,000 to 150,000 square feet) ranges from $80,000 to $85,000.

References:

DOE-ID, 1993. *Technology Name: Biological Destruction of Tank Wastes,* Technology Information Profile (Rev. 2) for ProTech, DOE ProTech Database, TTP Reference No.: ID-121204.

EPA, 1980. *Innovative and Alternative Technology Assessment Manual,* EPA, Office of Water Program Operations, EPA/430/9-78/009.

EPA, 1984. *Design Information on Rotating Biological Contactors,* EPA/600/2-84/106.

EPA, 1987. *Rotating Biological Contactors: U.S. Overview,* EPA/600/D-87/023.

EPA, 1991. *BioTrol — Biotreatment of Groundwater,* EPA RREL, series includes Technology Evaluation, EPA/540/5-91/001, PB92-110048; Applications Analysis, EPA/540/A5-91/001; Technology Demonstration Summary, EPA/540/S5-91/001; and Demonstration Bulletin, EPA/540/M5-91/001.

EPA, 1993. *BioTrol, Inc. — Methanotrophic Bioreactor System,* EPA RREL, series includes Emerging Technology Bulletin, EPA/540/F-93/506; Emerging Technology Summary, EPA/540/SR-93/505; and Journal Article, *AWMA*, Vol. 43, No. 11, November 1993.

Opatken, E.J., H.K. Howard, and J.J. Bond, 1987. *Biological Treatment of Hazardous Aqueous Wastes,* EPA Report EPA/600/D-87/184.

Opatken, E.J., H.K. Howard, and J.J. Bond, 1989. "Biological Treatment of Leachate from a Superfund Site," *Environmental Progress,* Vol. 8, No. 1.

Stinson, M., H. Skovronek, and T. Chresand, 1992. "EPA SITE Demonstration of BioTrol Aqueous Treatment System," *Journal of the Air Waste Management Association*, Vol. 41, No. 2, p. 228.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Hanscomb AFB, MA	Alison Thomas USAF Tyndall AFB, FL (904) 283-6303	Testing of constitutive TCE-degrading microbe	550 ppb TCE	About 85 ppb	NA
MacGillis & Gibbs New Brighton, MN	Dennis Chilcote BioTrol, Inc. 10300 Valley View Rd. Eden Prairie, MN 55344-3456 (612) 942-8032	SITE demo at Superfund site — BioTrol Aqueous Treatment System (BATS)	45 ppm PCP	<1 ppm in one pass	<$0.92/1,000 L (<$3.50/1,000 gallons)
TCE Site St. Joseph, MI	Ronald Lewis EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7856 Fax: (513) 569-7620	SITE demo of immobilized cell bioreactor (ICB) biotreatment system, aerobic/anaerobic fixed film bioreactor	TCE >100 ppm	Low ppbs	NA
Burleigh Tunnel Silver Plume, CO	Rick Brown Colorado Dept. of Health 4210 East 11th Ave. Room 252 (303) 692-3383 Fax: (303) 759-5355	Manmade wetland ecosystem-based treatment	50-60 ppm zinc	99% reduction in 3 months	NA
Dow Chemical Site, TX	Alison Thomas USAF Tyndall AFB	Chlorobenzene degradation in a fluid bed reactor	140 ppm chlorobenzene	<5 ppb chloro-benzene	NA

Note: NA = not available

Points of Contact:

Contact	Government Agency	Phone	Location
Edward Bates	EPA RREL	(513) 569-7774 Fax: (513) 569-7676	26 West M.L. King Dr. Cincinnati, OH 45268
David Smith	EPA, Region VIII	(303) 293-1475 Fax: (303) 294-1198	999 18th St. Denver, CO 80202
Edward J. Opatken	EPA RREL	(513) 569-7855	26 West M.L. King Dr. Cincinnati, OH 45268
Alison Thomas	USAF	(904) 283-6303	AL/EQW Tyndall AFB, FL 32403
Sherry Gibson	DOE	(301) 903-7258	EM-552, Trevion II Washington, DC 20585
Mary K. Stinson	EPA RREL	(908) 321-6683	2890 Woodbridge Ave. MS-104 Edison, NJ 08837-3679
Technology Demonstration and Transfer Branch	USAEC	(410) 612-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.44 AIR STRIPPING

Description: Air stripping is a full-scale technology in which volatile organics are partitioned from groundwater by greatly increasing the surface area of the contaminated water exposed to air. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

4-44 TYPICAL AIR STRIPPING SYSTEM

Air stripping involves the mass transfer of volatile contaminants from water to air. For groundwater remediation, this process is typically conducted in a packed tower or an aeration tank. The typical packed tower air stripper includes a spray nozzle at the top of the tower to distribute contaminated water over the packing in the column, a fan to force air countercurrent to the water flow, and a sump at the bottom of the tower to collect decontaminated water. Auxiliary equipment that can be added to the basic air stripper includes an air heater to improve removal efficiencies; automated control systems with sump level switches and safety features, such as differential pressure monitors, high sump level switches, and explosion-proof components; and air emission control and treatment systems, such as activated carbon units, catalytic oxidizers, or thermal oxidizers. Packed tower air strippers are installed either as permanent installations on concrete pads or on a skid or a trailer.

Aeration tanks strip volatile compounds by bubbling air into a tank through which contaminated water flows. A forced air blower and a distribution manifold are designed to ensure air-water contact without the need for any packing materials. The baffles and multiple units ensure adequate residence time for stripping to occur. Aeration tanks are typically sold as continuously operated skid-mounted units. The advantages offered by aeration tanks are considerably lower profiles (less than 2 meters or 6 feet high) than packed towers (5 to 12 meters or 15 to 40 feet high) where height may be a problem, and the ability to modify performance or adapt to changing feed composition by adding or removing trays or chambers. The discharge air from aeration tanks can be treated using the same technology as for packed tower air discharge treatment.

Air strippers can be operated continuously or in a batch mode where the air stripper is intermittently fed from a collection tank. The batch mode ensures consistent air stripper performance and greater energy efficiency than continuously operated units because mixing in the storage tanks eliminates any inconsistencies in feed water composition.

Applicability: Air stripping is used to separate VOCs from water. It is ineffective for inorganic contaminants. Henry's law constant is used to determine whether air stripping will be effective. Generally, organic compounds with constants greater than 0.01 atmospheres - m^3/mol are considered amenable to stripping. Some compounds that have been successfully separated from water using air stripping include BTEX, chloroethane, TCE, DCE, and PCE.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- The potential exists for inorganic (e.g., iron greater than 5 ppm, hardness greater than 800 ppm) or biological fouling of the equipment, requiring pretreatment or periodic column cleaning.
- Consideration should be given to the Henry's law constant of the VOCs in the water stream, and the type and amount of packing used in the tower.
- Compounds with low volatility at ambient temperature may require preheating of the groundwater.
- Off-gases may require treatment based on mass emission rate.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Vendors require the following information to select the properly sized tower for a specific application: range of feedwater flow rates; range of water and air temperatures; whether the tower will operate continuously or intermittently; tower feed and discharge systems (gravity feed or type and location of pumps); height restrictions on the tower; influent contaminant identification and concentrations; mineral content; pH; requirements for effluent water contaminant concentrations; and restrictions on air discharge from the tower.

Performance Data:

Removal efficiencies around 99% are typical for towers that have 4.6 to 6 meters (15 to 20 feet) of packing and are removing compounds amenable to stripping. Removal efficiencies can be improved by adding a second air stripper in series with the first, heating the contaminated water, increasing the air/liquid ratio, or heating the air. Thermal units for treating air stripper emissions can be used as a source of heat. The performance of aeration tanks can be improved by adding chambers or trays, or by increasing the air supply, depending on the design of the tank.

The major problem encountered with packed tower air strippers is fouling of the packing, which reduces the air flow rate. Fouling is caused by oxidation of minerals in the feed water, such as iron and magnesium, by precipitation of calcium, and by biological growth on the packing material.

Cost:

A major operating cost of air strippers is the electricity required for the groundwater pump, the sump discharge pump, and the air blower. The power rating of the groundwater pump and discharge pump depends on the pressure head and pressure drop across the column and should be obtained from pump curves. As a generalized rule, pumps in the 4 to 80 liters per minute (1 to 20-gpm) range require from 0.33 to 2 HP; from 80 to 290 liters per minute (20 to 75 gpm) power ratings are 1 to 5 HP; and from 380 to 2,270 liters per minute (100 to 600 gpm), power ratings range from 5 to 30 HP. A crude method of estimating blower motor power assumes that each foot of air stripper diameter requires 1.5 HP.

References:

Dietrich, C., D. Treichler, and J. Armstrong, 1987. *An Evaluation of Rotary Air Stripping for Removal of Volatile Organics from Groundwater,* USAF Environmental and Service Center Report ESL-TR-86-46.

Elliott, M.G. and E.G. Marchand, 1990. "USAF Air Stripping and Emissions Control Research," in *Proceedings of the 14th Annual Army Environmental Symposium,* USATHAMA Report CETHA-TE-TR-90055.

Shukla, H.M. and R.E. Hicks, 1984. *Process Design Manual for Stripping of Organics,* Water General Corporation for EPA, EPA/600/12-84/139, NTIS PB 84 232628.

Singh, S.P., 1989. *Air Stripping of Volatile Organic Compounds from*

Groundwater: An Evaluation of a Centrifugal Vapor-Liquid Contractor, USAF Environmental and Service Center Report ESL-TR-86-46.

Wilson, J.H., R.M. Counce, A.J. Lucero, H.L. Jennings, and S.P. Singh, 1991. *Air Stripping and Emissions Control Technologies: Field Testing of Counter Current Packings, Rotary Air Stripping, Catalytic Oxidation, and Adsorption Materials,* ESL TR 90-51.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
9th Ave. Superfund Site Gary, IN	Beth Fleming USAE-WES Attn: CEWES-EE-S 3909 Halls Ferry Road Vicksburg, MS 39180-6199 (601) 634-3943	Bench scale unit to treat VOCs in groundwater	NA	NA	NA
Englin AFB	Edward G. Marchand HQ AFCESA/RAVW Tyndall AFB, FL 32403-5319 (904) 283-6023	Field testing of rotary air stripper — high iron content	NA	>99% removal	NA
DOE - Savannah River Site	NA	500-gpm air stripper, 11 wells	15-ppm TCE, 6.7-ppm PCE	Less than 1 TCE and PCE	$0.20/1,000 L ($0.75/1,000 gallons)

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Capt. Edward G. Marchand	USAF	(904) 283-6023	HQ AFCESA/RAV Tyndall AFB, FL 32403-5319
Dr. James Heidman	EPA RREL	FTS 684-7632 (513) 569-7632	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.45 FILTRATION

Description: Filtration isolates solid particles by running a fluid stream through a porous medium. The driving force is either gravity or a pressure differential across the filtration medium. Pressure differentiated filtration techniques include separation by centrifugal force, vacuum, or positive pressure. Installation of filters in parallel is recommended so that groundwater extraction or injection pumps do not have to stop operating when filters are changed.

4-45 TYPICAL SCHEMATIC FOR FILTRATION OF CONTAMINATED GROUNDWATER

Applicability: Filtration is used mainly as a pretreatment or post-treatment process to remove suspended solids or precipitated metals.

Limitations: Factors that may affect the process include:

- The presence of oil and grease may interfere with the system by decreasing flow rate.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2

(Data Requirements for Groundwater, Surface Water, and Leachate).

Contaminant type and particle size will determine the filtration medium or membrane to be used.

Performance Data: Not available.

Cost: Typical costs for filtration range from $0.36 to $1.20 per 1,000 liters ($1.38 to $4.56 per 1,000 gallons) treated.

References:

EPA, 1990. *Dupont/Oberlin—Microfiltration System*, series includes Technology Evaluation, EPA/540/5-90/007, PB92-153410; Applications Analysis, EPA/ 540/A5-90/007; Technology Demonstration Summary, EPA/540/S5-90/007; and Demonstration Bulletin, EPA/540/M5-90/007.

EPA, 1990. *Innovative and Alternative Technology Assessment Manual*, EPA, Office of Water Program Operations, EPA/430/9-78/009.

EPA, 1992. *Atomic Energy of Canada Limited—Chemical Treatment and Ultrafiltration*, Emerging Technology Bulletin, EPA/540/F-92/002.

EPA, 1992. *SBP Technologies-Membrane Filtration*, Demonstration Bulletin, EPA/540/MR-92/014; and Applications Analysis, EPA/540/AR-92/014.

EPA, 1993. *Microfiltration Technology EPOC Water, Inc.*, Demonstration Bulletin, EPA/540/MR-93/513.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
American Creosote Works Pensacola, FL	EPA RREL John Martin 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7758	Positive pressure membrane hyperfiltration unit	PAHs, smaller phenolics	95%, <30% removal	$500K - $1.2M annual
Palmerton Zinc Superfund Site Palmerton, PA	John Martin EPA RREL (513) 569-7758	Pressure membrane microfiltration— shallow aquifer with dissolved heavy metals	Zinc and TSS	99.95% average	$213K - $549K annual
DOE Rocky Flats Golden, CO	Annette Gatchett EPA RREL (513) 569-7697	Colloid sorption filter for metals and nontritium radionuclides commercial scale SITE demo	Uranium in groundwater influent at filtration system concentration 40-100 mg/L	58-95% removal of uranium	$150K cap + $0.40 to $0.53/1,000 L ($1.50-$2.00/1,000 gallons)

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.46 ION EXCHANGE

Description: Ion exchange removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are attached. They also may be inorganic and natural polymeric materials. After the resin capacity has been exhausted, resins can be regenerated for re-use.

Principle of mixed-bed ion exchange: (a) Service period. (b) Backwash period. (c) Simultaneous regeneration. (Illinois Water Treatment Co.)

Source: *Chemical Engineer's Handbook*, Perry & Chilton (5th Edition)

4-46 94R-3318 9/13/94

4-46 TYPICAL ION EXCHANGE AND ADSORPTION EQUIPMENT DIAGRAM

Applicability: Ion exchange can remove dissolved metals and radionuclides from aqueous solutions. Other compounds that have been treated include nitrate, ammonia nitrogen, and silicate.

Limitations: Factors that may affect the applicability and effectiveness of this process include:

- Oil and grease in the groundwater may clog the exchange resin.
- Suspended solids content greater than 10 ppm may cause resin blinding.
- The pH of the influent water may affect the ion exchange resin selection.
- Oxidants in groundwater may damage the ion exchange resin.
- Wastewater is generated during the regeneration step and will require additional treatment and disposal.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Factors affecting the design of an ion exchange system include the presence of oil and grease, suspended solids, metals, oxidants, inorganic ions in groundwater; and pH of the groundwater.

Performance Data: DOE has developed compact processing units (CPUs), or "modular waste treatment units," which are relatively small mobile equipment modules. They perform unit chemical process operations. The CPUs allow rapid deployment of technologies for the treatment of radioactive wastes in underground storage tanks. The modules would be manufactured off-site by commercial vendors and moved into place using trucks or special transports. The concept of having standardized modules is based on the notion that various radioactive waste treatment subsystems could be standardized to match the CPU hardware package, leading to more rapid, cost-effective deployment. The cost benefits are realized even when multiple units are deployed to achieve greater processing rates. The modular design concept will also allow for reuse of CPU components for different unit processes or process deployments.

The ion-exchange CPU will pump undiluted liquid tank waste from an underground storage tank or receive liquid waste from a waste retrieval system for treatment. DOE Northwest Laboratories developed the CPU concept in FY91. Development of a cesium ion-exchange CPU technology is scheduled for 1996. A radioactive waste treatment demonstration is scheduled for FY97.

Another DOE technology, the resorcinol-formaldehyde ion exchange (ReFIX) resin, is being developed for prototype demonstration at the Hanford site in FY97. ReFIX resin is applicable to high-level wastestreams containing cesium-supernate salt solutions.

Cost: The cost for a typical ion exchange system ranges from $0.08 to $0.21 per 1,000 liters ($0.30 to $0.80 per 1,000 gallons) treated. Key cost factors include:

- Pretreatment requirements.
- Discharge requirements and resin utilization.
- Regenerant used and efficiency.

References: DOE, 1993. *Technology Name: Cesium Removal by Compact Processing Units for Radioactive Waste Treatment*, Technology Information Profile (Rev. 2) for ProTech, DOE ProTech Database, TTP Reference No.: RL-321221.

DOE, 1993. *Technology Name: Resorcinol-Formaldehyde Ion Exchange Resin for Elutable Ion Exchange in the Compact Portable Units (CPUs) Proposed at Hanford*, Technology Information Profile (Rev. 2) for ProTech, DOE ProTech Database, TTP Reference No.: SR-1320-02.

EPA, 1990. *Innovative and Alternative Technology Assessment Manual*, EPA, Office of Water Program Operations, EPA/430/9-78/009.

Points of Contact:

Contact	Government Agency	Phone	Location
Sherry Gibson	DOE	(301) 903-7258	EM-552, Trevion II Washington, DC 20585
John Burckle	EPA	(513) 569-7506	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.47 LIQUID PHASE CARBON ADSORPTION

Description: Liquid phase carbon adsorption is a full-scale technology in which groundwater is pumped through a series of vessels containing activated carbon to which dissolved contaminants adsorb. When the concentration of contaminants in the effluent from the bed exceeds a certain level, the carbon can be regenerated in place; removed and regenerated at an off-site facility; or removed and disposed of. Carbon used for explosives- or metals-contaminated groundwater probably cannot be regenerated and should be removed and properly disposed of. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes.

4-47 TYPICAL FIXED-BED CARBON ADSORPTION SYSTEM

The two most common reactor configurations for carbon adsorption systems are the fixed bed (see figure) and the pulsed or moving bed. The fixed-bed configuration is the most widely used for adsorption from liquids. Suspended solids in a liquid stream may accumulate in the column, causing an increase in pressure drop. When the pressure drop becomes too high, the accumulated solids must be removed, for example, by backwashing. The solids removal process necessitates adsorber downtime and may result in carbon loss and

disruption of the mass transfer zone. Pretreatment for removal of solids from streams to be treated is, therefore, an important design consideration.

Carbon can be used in conjunction with the steam reforming. Steam reforming is a technology designed to destroy halogenated solvents (such as carbon tetrachloride, CCl_4, and chloroform, $CHCl_3$) adsorbed on activated carbon by reaction with superheated steam in a commercial reactor (the Synthetica Detoxifier).

Applicability: The target contaminant groups for carbon adsorption are SVOCs and explosives. Limited effectiveness may be achieved on halogenated VOCs, fuels, and pesticides. Liquid phase carbon adsorption is effective for removing contaminants at low concentrations (less than 10 mg/L) from water at nearly any flow rate, and for removing higher concentrations of contaminants from water at low flow rates (typically 2 to 4 liters per minute or 0.5 to 1 gpm). Carbon adsorption is particularly effective for polishing water discharges from other remedial technologies to attain regulatory compliance. Carbon adsorption systems can be deployed rapidly, and contaminant removal efficiencies are high. Logistic and economic disadvantages arise from the need to transport and decontaminate spent carbon.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- The presence of multiple contaminants can impact process performance. Single component isotherms may not be applicable for mixtures. Bench tests may be conducted to estimate carbon usage for mixtures.
- Metals can foul the system.
- Costs are high if used as the primary treatment on wastestreams with high contaminant concentration levels.
- Type and pore size of the carbon, as well as the operating temperature, will impact process performance. Vendor expertise for carbon selection should be consulted.
- Carbon used for explosives-contaminated groundwater is not regenerated; it must be properly disposed of.
- Water-soluble compounds and small molecules are not adsorbed well.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

The major design variables for liquid phase carbon applications are empty

bed contact time (EBCT), usage rate, and system configuration. Particle size and hydraulic loading are often chosen to minimize pressure drop and reduce or eliminate backwashing. System configuration and EBCT have an impact on carbon usage rate. When the bed life is longer than 6 months and the treatment objective is stringent ($C_e/C_o<0.05$), a single adsorber or a combination of single beds operating in parallel is preferred. For a single adsorber, the EBCT is normally chosen to be large enough to minimize carbon usage rate. When less stringent objectives are required ($C_e/C_o<0.3$), blending of effluents from partially saturated adsorbers can be used to reduce carbon replacement rate. When stringent treatment objectives are required ($C_e/C_o<0.05$) and bed life is short (less than 6 months), multiple beds in series may be used to decrease carbon usage rate.

Performance Data:

Adsorption by activated carbon has a long history of use as a treatment for municipal, industrial, and hazardous wastestreams. The concepts, theory, and engineering aspects of the technology are well developed. It is a proven technology with documented performance data. Carbon adsorption is a relatively nonspecific adsorbent and is effective for removing many organic, explosive, and some inorganic contaminants from liquid and gaseous streams.

Cost:

Costs associated with GAC are dependent on wastestream flow rates, type of contaminant, concentrations, and site and timing requirements. Costs are lower with lower concentration levels of a contaminant of a given type. Costs are also lower at higher flow rates. At flow rates of 0.4 million liters per day (0.1 mgd), costs increase to $0.32 to $1.70 per 1,000 liters ($1.20 to $6.30 per 1,000 gallons) treated.

References:

EPA, 1986. *Mobile Treatment Technologies for Superfund Wastes,* EPA/540/2-86/003.

EPA, 1990. *Innovative and Alternative Technology Assessment Manual,* EPA, Office of Water Program Operations, EPA/430/9-78/009.

EPA, 1993. *Approaches for the Remediation of Federal Facility Sites Contaminated with Explosive or Radioactive Wastes,* EPA/625/R-93/013.

Zappi, M.E., B.C. Fleming, and C.L. Teetar, 1992. *Draft - Treatability of Contaminated Groundwater from the Lang Superfund Site,* USAE-WES.

Zappi, M.E., C.L. Teeter, B.C. Fleming, and N.R. Francingues, 1991. *Treatability of Ninth Avenue Superfund Site Groundwater,* WES Report EL-91-8.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Verona Wellfield Battle Creek, MI	NA	Superfund - GAC as pretreatment for air stripper.	12,850 ppb TVOC	11 ppb	NA
U.S. Coast Guard Traverse City, MI	NA	Pump/treat and discharge to municipal sewer.	10,329 ppb Toluene	<10 ppb	NA
Love Canal Niagara Falls, NY	NA	GAC system for leachate treatment.	28,000 ppb Benzene	<10 ppb	NA
Milan AAP Milan, TN	USAEC ETD (410) 671-2054	Pilot scale study of GAC for explosives-contaminated groundwater.	1.0 - 2.0 mg/L total explosives	ND (<10 ppb) for all 9 explosives	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Dr. James Heidman	EPA RREL	FTS 684-7632 (513) 569-7632	26 West M.L. King Dr. Cincinnati, OH 45268
David Biancosino	DOE	(301) 903-7961	EM-551, Trevion II Washington, DC 20585
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4.48 PRECIPITATION

Description: Precipitation of metals has long been the primary method of treating metal-laden industrial wastewaters. As a result of the success of metals precipitation in such applications, the technology is being considered and selected for use in remediating groundwater containing heavy metals, including their radioactive isotopes. In groundwater treatment applications, the metal precipitation process is often used as a pretreatment for other treatment technologies (such as chemical oxidation or air stripping) where the presence of metals would interfere with the other treatment processes.

4-48 TYPICAL METALS PRECIPITATION PROCESS

Metals precipitation from contaminated water involves the conversion of soluble heavy metal salts to insoluble salts that will precipitate. The precipitate can then be removed from the treated water by physical methods such as clarification (settling) and/or filtration.

This process transforms dissolved contaminant into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. The process usually uses pH adjustment, addition of a chemical precipitant, and flocculation. Typically, metals precipitate from the solution as hydroxides, sulfides, or carbonates. The solubilities of the specific metal contaminants and the required cleanup standards will dictate the process used.

Applicability: Precipitation is used mainly for metals.

Limitations: Disadvantages of metals precipitation may include:

- As with any pump and treat process, if the source of contamination is not removed (as in metals absorbed to soil), treatment of the groundwater may be superfluous.
- The presence of multiple metal species may lead to removal difficulties as a result of amphoteric natures of different compounds (i.e., optimization on one metal species may prevent removal of another).
- As discharge standards become more stringent, further treatment may be required.
- Metal hydroxide sludges must pass TCLP prior to land disposal.
- Reagent addition must be carefully controlled to preclude unacceptable concentrations in treatment effluent.
- Efficacy of the system relies on adequate solids separation techniques (e.g., clarification, flocculation, and/or filtration).
- Process may generate toxic sludge requiring proper disposal.
- Process can be costly, depending on reagents used, required system controls, and required operator involvement in system operation.
- Dissolved salts are added to the treated water as a result of pH adjustment.
- Polymer may be added to the water to achieve adequate settling of solids.
- Treated water will often require pH adjustment.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Bench-scale treatability tests should be conducted to determine operating parameters and characteristics [i.e., reagent type and dosage, optimum pH, retention time, flow rate, temperature, mixing requirements, flocculent (polymer) selection, suspended solids, precipitate settling and filtration rates, and sludge volume and characteristics].

Performance

Data:

Precipitation of heavy metals as the metal hydroxides or sulfides has been practiced as the prime method of treatment for heavy metals in industrial wastewater for many years. More recently, precipitation (usually as the metal hydroxides) has been used in the electronics and electroplating industries as a pretreatment technology for wastewater discharge to a publicly owned treatment works (POTW). Metals precipitation is widely used to meet NPDES requirements for the treatment of heavy metal-containing wastewaters.

Because of its success in meeting requirements for discharge of treated wastewater, metals precipitation is recognized as a proven process for use in remedial activities such as groundwater treatment. Precipitation (combined with sedimentation, and/or flocculation and filtration) is becoming the most widely selected means for heavy metals removal from groundwater in pump and treat operations.

Cost:

The primary capital cost factor is design flow rate. Capital costs for 75- and 250-liters-per-minute (20-gpm and 65-gpm) packaged metals precipitation systems are approximately $85,000 and $115,000, respectively.

The primary factors affecting operating costs are labor and chemical costs. Operating costs (excluding sludge disposal) are typically in a range from $0.08 to $0.18 per 1,000 liters ($0.30 to $0.70 per 1,000 gallons) of groundwater containing up to 100 mg/L of metals.

For budgetary purposes, sludge disposal may be estimated to increase operating costs by approximately $0.13 per 1,000 liters ($0.50 per 1,000 gallons) of groundwater treated. Actual sludge disposal costs (including fixation and transportation) have been estimated at approximately $330 per metric ton ($300 per ton) of sludge.

Costs for performing a laboratory treatability study for metals precipitation may range from $5,000 to $20,000. Depending on the degree of uncertainty or other requirements, a pilot or field demonstration may be needed. Associated costs may range from $50,000 to $250,000 (depending on scale, analytical requirements, and duration).

References:

Balaso, C.A., et al., 1986. *Soluble Sulfide Precipitation Study,* Arthur D. Little, Inc., Final Report to USATHAMA, Report No. AMXTH-TE-CR-87106.

Bricka, R. Mark, 1988. *Investigation and Evaluation of the Performance of Solidified Cellulose and Starch Xanthate Heavy Metal Sludges,* USACE-WES Technical Report EL-88-5.

EPA, 1980. *Control and Treatment Technology for the Metal Finishing Industry: Sulfide Precipitation,* EPA/625/8-80/003.

EPA, 1990. *Innovative and Alternative Technology Assessment Manual*. EPA, Office of Water Program Operations, EPA/430/9-78/009.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Coakley Landfill New Hampshire	NA	Pretreatment of groundwater by hydroxide precipitation with lime, then air stripping for removal of VOCs	Cr - 330 ppb Ni - 122-200 ppb As - 10-90 ppb	Cr - 50 ppb Ni - 100 ppb As - 50 ppb	NA
Stringfellow Acid Pit Site California	NA	Pretreatment for the removal of metals and organics, then POTW	Cr - 1.5-270 ppm Cd - 0.32-9.3 ppm Zn - 2.2-300 ppm Cu - 1.7-20 ppm	Cr - 0.5 ppm Cd - 0.11 ppm Zn - 2.61 ppm Cu - 2 ppm	NA
Winthrop Landfill Winthrop, ME	NA	Pilot test of metals from the groundwater by precipitation	As - 0.1-0.8 ppm Ni - 0.04 ppm Zn - 0.2-0.6 ppm	As - 0.05 ppm Ni - 0.04 ppm Zn - 0.18 ppm	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
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R.L. Biggers	NFESC	(805) 982-2640	Code 414 Port Hueneme, CA 93043
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.49 ULTRAVIOLET (UV) OXIDATION

Description: UV oxidation is a destruction process that oxidizes organic and explosive constituents in wastewaters by the addition of strong oxidizers and irradiation with UV light. The oxidation reactions are achieved through the synergistic action of UV light, in combination with ozone (O_3) and/or hydrogen peroxide (H_2O_2). If complete mineralization is achieved, the final products of oxidation are carbon dioxide, water, and salts. The main advantage of UV oxidation is that it is a destruction process, as opposed to air stripping or carbon adsorption, for which contaminants are extracted and concentrated in a separate phase. UV oxidation processes can be configured in batch or continuous flow modes, depending on the throughput under consideration.

4-49 TYPICAL UV/OXIDATION GROUNDWATER TREATMENT SYSTEM

Applicability: Practically any organic contaminant that is reactive with the hydroxyl radical can potentially be treated. A wide variety of organic and explosive contaminants are susceptible to destruction by UV/oxidation, including petroleum hydrocarbons; chlorinated hydrocarbons used as industrial solvents and cleaners; and ordnance compounds such as TNT, RDX, and HMX. In many cases, chlorinated hydrocarbons that are resistant to biodegradation may be effectively treated by UV/oxidation. Typically, easily oxidized organic compounds, such as those with

double bonds (e.g., TCE, PCE, and vinyl chloride), as well as simple aromatic compounds (e.g., toluene, benzene, xylene, and phenol), are rapidly destroyed in UV/oxidation processes.

Limitations: Limitations of UV/oxidation include:

- The aqueous stream being treated must provide for good transmission of UV light (high turbidity causes interference). This factor can be critical for UV/H_2O_2 than UV/O_3. (Turbidity does not affect direct chemical oxidation of the contaminant by H_2O_2 or O_3.)

- Free radical scavengers can inhibit contaminant destruction efficiency. Excessive dosages of chemical additives may act as a scavenger.

- The aqueous stream to be treated by UV/oxidation should be relatively free of heavy metal ions (less than 10 mg/L) and insoluble oil or grease to minimize the potential for fouling of the quartz sleeves.

- When UV/O_3 is used on volatile organics such as TCA, the contaminants may be volatilized (e.g., "stripped") rather than destroyed. They would then have to be removed from the off-gas by activated carbon adsorption or catalytic oxidation.

- Costs may be higher than competing technologies because of energy requirements.

- Pretreatment of the aqueous stream may be required to minimize ongoing cleaning and maintenance of UV reactor and quartz sleeves.

- Handling and storage of oxidizers require special safety precautions.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Design and operational parameters include contact or retention time, oxidizer influent dosages, pH, temperature, UV lamp intensity, and various catalysts.

Performance Data: The UV/oxidation is an innovative groundwater treatment technology that has been used in full-scale groundwater treatment application for more than 10 years. Currently, UV/oxidation processes are in operation in more than 15 full-scale remedial applications. A majority of these applications are for groundwater contaminated with petroleum products or with a variety of industrial solvent-related organics such as TCE, DCE, TCA, and vinyl chloride.

A wide range of sizes of UV/oxidation systems are commercially available.

Single-lamp benchtop reactors that can be operated in batch or continuous modes are available for the performance of treatability studies. Pilot and full-scale systems are available to handle higher throughput (e.g., 3,800 to 3,800,000 liters or 1,000 to 1,000,000 gallons per day).

Cost: Costs generally are between $0.03 to $3.00 per 1,000 liters ($0.10 to $10.00 per 1,000 gallons). Factors that influence the cost to implementing UV/oxidation include:

- Types and concentration of contaminants (as they affect oxidizer selection, oxidizer dosage, UV light intensity, and treatment time).
- Degree of contaminant destruction required.
- Desired water flow rates.
- Requirements for pretreatment and/or post-treatment.

References:

Buhts, R., P. Malone, and D. Thompson, 1978. *Evaluation of Ultra-Violet/Ozone Treatment of Rocky Mountain Arsenal (RMA) Groundwater*, USAE-WES Technical Report No. Y-78-1.

Christman, P.L. and A.M. Collins, April 1990. "Treatment of Organic Contaminated Groundwater by Using Ultraviolet Light and Hydrogen Peroxide," in *Proceedings of the Annual Army Environmental Symposium*, USATHAMA Report CETHA-TE-TR-90055.

EPA, 1989. *Ultrox International — UV Ozone Treatment for Liquids*, EPA RREL, series includes Technology Evaluation, EPA/540/5-89/012, PB90-198177; Applications Analysis, EPA/540/A5-89/012; Technology Demonstration Summary, EPA/540/S5-89/012; and Demonstration Bulletin, EPA/540/MS-89/012.

EPA, 1990. *Innovative and Alternative Technology Assessment Manual*, EPA, Office of Water Program Operations, EPA/430/9-78/009.

EPA, 1993. *Magnum Water Technology — CAV-OX Ultraviolet Oxidation Process*, EPA RREL, Demonstration Bulletin, EPA/540/MR-93/520; and Applications Analysis, EPA/540/AR-93/520.

EPA, 1993. *Perox-Pure™ Chemical Oxidation Treatment*, EPA RREL, series includes Demonstration Bulletin, EPA/540/MR-93/501; Applications Analysis, EPA/540/AR-93/501; Technology Evaluation, EPA/540/R-93/501, PB93-213528; and Technology Demonstration Summary, EPA/540/SR-93/501.

EPA, 1993. *PURUS, Inc. — Destruction of Organic Contaminants in Air Using Advanced Ultraviolet Flashlamps*, EPA RREL, series includes

Emerging Technology Bulletin, EPA/540/F-93/501; Emerging Technology Summary, EPA/540/SR-93/516; and Emerging Technology Report, EPA/540/R-93/516, PB93-205383.

Zappi, M.E., et al., April 1990. "Treatability Study of Four Contaminated Waters at Rocky Mountain Arsenal, Commerce City, Colorado, Using Oxidation with Ultra-Violet Radiation Catalyzation," in *Proceedings of the 14th Annual Army Environmental Symposium,* USATHAMA Report CETHA-TE-TR-90055.

Zappi, M.E. and B.C. Fleming, 1991. *Treatability of Contaminated Groundwater from the Lang Superfund Site,* Draft WES Report, USAE-WES, Vicksburg, MS.

Zappi, M.E., B.C. Fleming, and M.J. Cullinane, 1992. "Treatment of Contaminated Groundwater Using Chemical Oxidation," in *Proceedings of the 1992 ASCE Water Forum Conference,* Baltimore, MD.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Munitions Washout Lagoon Submarine Base Bangor, WA	Laura Yeh, NFESC Code 411 Port Hueneme, CA 93043 (805) 982-1660	Bench-scale TNT and RDX treatability test. Recirculating UV/ozone reactor. 30-minute retention.	7 ppm TNT; 600 ppb RDX	0.25 ppb; 0.50 ppb	<$0.40 per 1,000 L (<$1.50/1,000 gallons)
Winthrop Superfund Site, ME	Dr. Raymond Machacek Arthur D. Little, Inc. (617) 498-5580	On-site demo - pretreat for iron, then UV/oxidation solvents.	5 ppm DMF	5 ppb	NA
Milan AAP Milan, TN	USAEC ETD (410) 671-2054	Pilot scale tests of UV/OX for explosivescontaminated groundwater.	20.0 ppm total explosives	ND (<10 ppb) for all explosives	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Mark E. Zappi	USAE WES	(601) 634-2856	3903 Halls Ferry Road Vicksburg, MS 39180-6199
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R.L. Biggers	NFESC	(805) 982-4856	Code 414 Port Hueneme, CA 93043
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.50 NATURAL ATTENUATION

Description: Natural subsurface processes — such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials — are allowed to reduce contaminant concentrations to acceptable levels. Natural attenuation is not a "technology" per se, and there is significant debate among technical experts about its use at hazardous waste sites. Consideration of this option requires modeling and evaluation of contaminant degradation rates and pathways. The primary objective of site modeling is to demonstrate that natural processes of contaminant degradation will reduce contaminant concentrations below regulatory standards before potential exposure pathways are completed. In addition, sampling and sample analysis must be conducted throughout the process to confirm that degradation is proceeding at rates consistent with meeting cleanup objectives.

4-50 TYPICAL MONITORING WELL CONSTRUCTION DIAGRAM

Natural attenuation is not the same as "no action," although it often is perceived as such. CERCLA requires evaluation of a "no action" alternative but does not require evaluation of natural attenuation. Natural attenuation is considered in the Superfund program on a case-by-case basis, and guidance on its use is still evolving. It has been selected at Superfund sites where, for example, removal of DNAPLs has been determined to be technically impracticable (Superfund is developing technical impracticability (TI)

guidance); and where it has been determined that active remedial measures would be unable to significantly speed remediation time frames. Where contaminants are expected to remain in place over long periods of time, TI waivers must be obtained. In all cases, extensive site characterization is required.

The attitude toward natural attenuation varies among agencies. USAF carefully evaluates the potential for use of natural attenuation at its sites; however, EPA accepts its use only in certain special cases.

Applicability: Target contaminants for natural attenuation are nonhalogenated VOCs and SVOCs and fuel hydrocarbons. Halogenated VOCs and SVOCs and pesticides also can be allowed to naturally attenuate, but the process may be less effective and may be applicable to only some compounds within these contaminant groups.

Limitations: Factors that may limit applicability and effectiveness include:

- Data must be collected to determine model input parameters.
- Intermediate degradation products may be more mobile and more toxic than the original contaminant.
- Natural attenuation should be used only in low-risk situations.
- Contaminants may migrate before they are degraded.
- The site may have to be fenced and may not be available for reuse until contaminant levels are reduced.
- If free product exists, it may have to be removed.
- Some inorganics can be immobilized, such as mercury, but they will not be degraded.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Groundwater, Surface Water, and Leachate).

Many potential suppliers can perform the modeling, sampling, and sample analysis required for justifying and monitoring natural attenuation. The extent of contaminant degradation depends on a variety of parameters, such as contaminant types and concentrations, temperature, moisture, and availability of nutrients/electron acceptors (e.g., oxygen, nitrate).

When available, information to be obtained during data review includes:

- Soil and groundwater quality data:
  - Three-dimensional distribution of residual-, free-, and dissolved-phase contaminants. The distribution of residual- and free-phase

contaminants will be used to define the dissolved-phase plume source area.

- Groundwater and soil geotechnical data.

- Historical water quality data showing variations in contaminant concentrations through time.

- Chemical and physical characteristics of the contaminants.

- Potential for biodegradation of the contaminants.

· Geologic and hydrogeologic data:

- Lithology and stratigraphic relationships.
- Grain-size distribution (sand versus silt versus clay).
- Aquifer hydraulic conductivity.
- Flow gradient.
- Preferential flow paths.
- Interaction between groundwater and surface water.

· Location of potential receptors:

- Groundwater wells.
- Surface water discharge points.

Performance Data: Natural attenuation has been selected by AFCEE for remediation at 45 sites.

Cost: There are costs for modeling contamination degradation rates, to determine whether natural attenuation is a feasible remedial alternative, for subsurface sampling and sample analysis (potentially extensive) to determine the extent of contamination and confirm contaminant degradation rates and cleanup status, and for migration and degradation monitoring.

References:

Barker, J.F., et al., 1987. "Natural Attenuation of Aromatic Hydrocarbons in a Shallow Sand Aquifer," *Groundwater Monitoring Review,* Winter 1987.

Bredehoeft, J.D., and L.F. Konikow, 1993. "Ground-Water Models - Validate or Invalidate," *Ground Water*, Vol. 31, No. 2, pp. 178-179.

Bruce, L., T. Miller, and B. Hockman, 1991. "Solubility Versus Equilibrium Saturation of Gasoline Compounds - A Method To Estimate Fuel/Water Partition Coefficient Using Solubility or K_{oc}", in *Proceedings of the NWWA/API Conference on Petroleum Hydrocarbons in Ground Water*, A. Stanley, Editor, NWWA/API, pp. 571-582.

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Weidemeier, T.H., P.R. Guest, R.L. Henry, and C.B. Keith, 1993. "The Use of Bioplume To Support Regulatory Negotiations at a Fuel Spill Site Near Denver, Colorado," in *Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Groundwater Prevention, Detection, and Restoration Conference*, NWWA/API, pp. 445-449.

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Weidemeier, T.H., D.C. Downey, J.T. Wilson, D.H. Kampbell, R.N. Miller, and J.E. Hansen, 1994. *Technical Protocol for Implementing the Intrinsic Remediation (Natural attenuation) with Long-Term Monitoring Option for Dissolved-Phase Fuel Contamination in Ground Water*, AFCEE, San Antonio, TX.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Columbus AFB, MS	Tom deVenoge, USAF Tyndall AFB, FL (904) 283-6205	Controlled releases of various hydrocarbons were extensively monitored and modeled over time	NA	NA	NA
Hill AFB, VT	AFCEE	NA	NA	NA	NA
Eglin AFB, FL	AFCEE	NA	NA	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Gov Agency	Phone	Location
Tom deVenoge	USAF	(904) 283-6205	AL/EQW Tyndall AFB, FL 32403
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.51 BIOFILTRATION

Description: Biofiltration is a full-scale technology in which vapor-phase organic contaminants are passed through a soil bed and sorb to the soil surface where they are degraded by microorganisms in the soil. Specific strains of bacteria may be introduced into the filter and optimal conditions provided to preferentially degrade specific compounds. The biofilter provides several advantages over conventional activated carbon adsorbers. First, bio-regeneration keeps the maximum adsorption capacity available constantly; thus, the mass transfer zone remains stationary and relatively short. The filter does not require regeneration, and the required bed length is greatly reduced. These features reduce capital and operating expenses. Additionally, the contaminants are destroyed not just separated, as with GAC technologies.

4-51 TYPICAL METHANOTROPHIC BIOFILM REACTOR DIAGRAM

Applicability: As with other biological treatment processes, biofiltration is highly dependent upon the biodegradability of the contaminants. Under proper conditions, biofilters can remove virtually all selected contaminants to harmless products. Biofiltration is used primarily to treat nonhalogenated VOCs and fuel hydrocarbons. Halogenated VOCs also can be treated, but the process may be less effective. Biofilters have been successfully used to control odors from compost piles.

Limitations: The following factors may limit the applicability and effectiveness of the process:

- The rate of influent air flow is constrained by the size of the biofilter.
- Fugitive fungi may be a problem.
- Low temperatures may slow or stop removal unless the biofilter is climate-controlled.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.3 (Data Requirements for Air Emissions/Off-Gases).

Performance Data: Nonproprietary filters that require low air loading rates for organics (?100 ppm) have been used successfully for more than 20 years. Proprietary designs that support higher air loadings also are available. Biofilters have been used extensively in Europe and Japan, but only recently have they received attention in the United States.

Moisture levels, pH, temperature, and other filter conditions may have to be monitored to maintain high removal efficiencies. Filter flooding and plugging as a result of excessive biomass accumulation may require periodic mechanical cleaning of the filter.

Cost: Cost estimates range from $5 to $10 per kilogram of contaminant ($2.27 to $4.54 per pound).

References: Not available.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
SITE Emerging Technology (Membrane Technology and Process, Inc.)	Naomi Barkley EPA RREL 26 West M.L. King Dr. Cincinnati, OH 45268 (513) 569-7854 Fax: (513) 569-7620	Bench-scale "bioscrubber"	10-20 ppm Toluene	> 95% removal	NA
SITE Emerging Technology (Remediation Technologies, Inc.)	Fred Bishop EPA RREL (513) 569-7629 Fax: (513) 569-7105	Immobilized film bioreactor (gas-phase biofilter at bench and pilot-scale)	10-1,000 ppm VOCs	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.52 HIGH ENERGY CORONA

Description: The High Energy Corona (HEC) technology is being developed by DOE as one of many approaches toward decontaminating soil off-gases prior to atmospheric release. The objective of the HEC technology is to provide a standalone, field-portable means of treating soil off-gases produced during soil treatment operations.

4-52 TYPICAL LOW TEMPERATURE PLASMA REACTOR

The HEC process uses high-voltage electricity to destroy VOCs at room temperature. The equipment consists of the following: an HEC reactor in which the VOCs are destroyed; inlet and outlet piping containing process instrumentation to measure humidity, temperature, pressure, contaminant concentration, and mass flow rate; a means for controlling inlet flow rates and inlet humidity; and a secondary scrubber.

The HEC reactor is a glass tube filled with glass beads through which the pretreated contaminated off-gas is passed. Each reactor is 2 inches in diameter, 4 ft long, and weighs less than 20 pounds. A high voltage electrode is placed along the centerline of the reactor, and a grounded metal screen is attached to the outer glass surface of the reactor. A high-voltage power supply is connected across the electrodes to provide 0 to 50 mA of 60-Hz electricity at 30 kV. The electrode current and power depend upon the type and concentration of contaminant.

The technology is packaged in a self-contained mobile trailer that includes gas handling equipment and on-line analytical capabilities. Installation consists of connecting inlet and outlet hoses to the HEC process trailer. Training in the use of the equipment can usually be accomplished well within

1 hour. Failure control is provided by a combination of automated and manually activated means, addressing electrical failure, loss of flow, and loss of VOC containment caused by breakage of the glass reactor vessel. The HEC process can be operated with little, if any, maintenance required. Neither catastrophic failure nor any diminishing in levels of performance have been observed through months of periodic operation in the laboratory. The on-line gas chromatograph and process instruments do require periodic recalibration to ensure data quality.

Applicability: Contaminants that can be treated include most or all VOCs and SVOCs. The potential also exists for treating inorganic compounds, such as oxides of nitrogen and oxides of sulfur. This technique is specifically useful for destroying organics and chlorinated solvents such as trichloroethylene (TCE), tetrachloroethylene (PCE), carbon tetrachloride, chloroform, diesel fuel, and gasoline. Both gas and liquid phase contaminants are treatable.

Limitations: Continued research and development (R&D) is planned to accomplish the following: fully characterize the reactor emissions to complete mass balances; adapt the HEC process to complete real-time control; better understand the physical and chemical phenomena that make the HEC process work; develop larger reactors; and optimize the hardware and packaging associated with the technology for specific, as well as modular or generic, treatment applications.

Data Needs: A detailed discussion of data elements is provided in Subsection 2.2.3 (Data Requirements for Air Emissions/Off-Gases).

Performance Data: The HEC technology can destroy more than 99.9% TCE. The technology destroys PCE to a level of 90 to 95%. In preliminary tests with heptane, destruction levels appear to be extremely high, but have not been quantified. When chlorinated VOCs are treated, water containing either sodium hydroxide or baking soda is recirculated in a scrubber to remove acid gases, hydrochloric acid, and chlorine from the reactor effluent. It should also be noted that further contaminant destruction appears likely in this wet scrubber. This is presumably because of strong gaseous oxidants that exit the HEC reactor. Typical outlet properties would be nondetectable concentrations of TCE, ozone, hydrochloric acid, phosgene, and chlorine, with up to 1 ppmv NO_x (below regulatory limits). Air exits the HEC process at temperatures of 100 ?C or lower or slightly above ambient temperature if a wet scrubber is used. A scrub solution (containing less than 10-wt% sodium chloride in water) is produced when chlorinated VOCs are treated.

One reactor processes up to 5 scfm of soil off-gas. The HEC field-scale process demonstrated at Savannah River uses 21 HEC reactors in parallel to treat up to 105 scfm of contaminated off-gas. A typical application will involve an inlet stream containing 1,800 ppmb of TCE in humid air at 10 to 20 ?C. Power input is typically 50 to 150 W/scfm being processed. For dry inlet streams, deionized water is added as steam to produce an inlet humidity (hr) of 60 to 80%. Less than 20 mL per minute of water is required to humidify a completely dry stream at a flow of 105 scfm. For water-saturated

inlet streams, the stream is preheated (using electric heaters) to lower the hr from 100% to 80%. In many cases, the vapor-extraction blower associated with retrieving the VOCs from soil will sufficiently preheat the soil off-gas to 80% or lower so that no further preheating is required.

Discussions with manufacturers/licensees have been initiated with the belief that HEC is now ready for commercial availability. The 105-scfm field prototype is available now for commercial testing and evaluation. Pacific Northwest Laboratory (PNL) is continuing R&D to improve and scale the technology. Scaleup to 50 scfm per reactor seems feasible for extremely large applications.

Cost: Initial outlay for a 105 scfm process, the prototype field treatment system, is $50,000. As with any other technology, large-scale production and customization would significantly reduce costs, perhaps to as low as $20,000. Labor requirements are projected as 0.25 fulltime equivalent. Energy requirements are $27 per day, or roughly $0.35 per pound of contaminant. Total cost is roughly $10 per pound of contaminant, including a 25% contingency to account for any unknown additional costs. Although maintenance costs are minimal, the total cost figure assumes 8% downtime and a capital payback period of 6 months.

References:

DOE-RL, 1993. *Technology Name: High-Energy Corona*, Technology Information Profile (Rev. 2) for ProTech, DOE ProTech Database, TTP Reference No.: RL-3211-01.

TNA-II OTD/OER Crosswalk Worksheet, 1992, "High-Energy Corona for Destruction of VOCs in Process Off Gases," *The 1993 Technology Needs Crosswalk Report*, Vol. 3, Appendix H, TTP Reference No.: RL-3211-01, Richland, WA, TRL009.

Virden, J.W., W.O. Heath, S.C. Goheen, M.C. Miller, G.M. Mong, and R.L. Richardson, 1992. "High-Energy Corona for Destruction of Volatile Organic Contaminants in Process Off-Gases," in *Proceedings of Spectrum '92 International Topical Meeting on Nuclear and Hazardous Waste Management*, Vol. 2, pp. 670-673, 23-27 August 1992, Boise, ID.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
DOE Savannah River	DOE	Field Scale Process	NA	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
David Biancosino	DOE	(301) 903-7961	EM-551, Trevion II Washington, DC 20585
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.53 MEMBRANE SEPARATION

Description: A high pressure membrane separation system has been designed by DOE to treat feedstreams that contain dilute concentrations of VOCs. The organic vapor/air separation technology involves the preferential transport of organic vapors through a nonporous gas separation membrane (a diffusion process analogous to pumping saline water through a reverse osmosis membrane). In this system, the feedstream is compressed and sent to a condenser where the liquid solvent is recovered. The condenser bleed stream, which contains approximately 5,000 ppm of the VOC, is then sent to the membrane module.

The membrane module is comprised of spiral-wound modules of thin film membranes separated by plastic mesh spacers. The membrane and the spacers are wound spirally around a central collection pipe. In the membrane module the stream is further concentrated to 3% VOC. The concentrated stream is then returned to the compressor for further recovery in the condenser.

4-53 TYPICAL MEMBRANE SEPARATION DIAGRAM

Applicability: The targeted contaminants are VOCs, carbon tetrachloride, and chloroform in gas streams.

Limitations: Limitations of this technology are:

- Inability to handle fouling constituents in soil.
- Inability to handle fluctuations in VOC concentrations.

Data Needs: A detailed discussion of data elements is provided in Subsection 2.2.3 (Data Requirements for Air Emissions/Off Gases).

Performance Data: This technology is being tested at a Hanford site where VOCs will be obtained by vacuum extraction. Carbon tetrachloride and chloroform will preferentially be removed from the gas stream. Based upon a VOC effluent concentration of 1,000 ppm, there is a 95% removal efficiency. The remaining 5% is polished using carbon adsorption. Future work involves sizing the pilot plant to handle fluctuations in the VOC concentrations and fouling of the membrane with other constituents.

Cost: Capital equipment (7,000 scfm) is $2.5 million; O&M is $6,000 (replacement every 3 years). Information on life-cycle will be available upon completion of testing, and emissions treatment is $2,000 to $5,000 per pound of VOC recovered.

References:

DOE-RL, 1993. *Technical Name: VOC Offgas Membrane Separation*, Technology Information Profile (Rev. 3), DOE ProTech Database, TTP Reference No.: RL-9740.

EPA, 1992. *SBP Technologies — Membrane Filtration*, EPA RREL, Demonstration Bulletin, EPA/540/MR-92/014; and Applications Analysis, EPA/540/AR-92/014.

EPA, 1994. *Membrane Technology and Research, Inc.— Volatile Organic Compound Removal from Air Streams by Membrane Separations*, EPA RREL, Emergency Technology Bulletin, EPA/540/F-94/503.

EPA, 1994. *Volatile Organic Compound Removal from Air Streams by Membrane Separation*, EPA RREL, Emerging Technology Bulletin, EPA/540/F-94/503.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
DOE Hanford	DOE	Field Testing	1,000 ppm VOC	95% removal	$2.5M cap; $6K annual

Points of Contact:

Contact	Government Agency	Phone	Location
David Biancosino	DOE	(301) 903-7961	EM-551, Trevion II Washington, DC 20585
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

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4.54 OXIDATION

Description: Oxidation equipment (thermal or catalytic) is used for destroying contaminants in the exhaust gas from air strippers and SVE systems. **Thermal oxidation** units are typically single chamber, refractory-lined oxidizers equipped with a propane or natural gas burner and a stack. Lightweight ceramic blanket refractory is used because many of these units are mounted on skids or trailers. If gasoline is the contaminant, heat exchanger efficiencies are limited to 25 to 35%, and preheat temperatures are maintained below 180 ?C (530 ?F) to minimize the possibility of ignition occurring in the heat exchanger. Flame arrestors are always installed between the vapor source and the thermal oxidizer. Burner capacities in the combustion chamber range from 0.5 to 2 million Btus per hour. Operating temperatures range from 760 to 870 ?C (1,400 to 1,600 ?F), and gas residence times are typically 1 second or less.

4-54 TYPICAL OXIDATION SYSTEM

Catalytic oxidation is a relatively recently applied alternative for the treatment of VOCs in air streams resulting from remedial operations. The addition of a catalyst accelerates the rate of oxidation by adsorbing the oxygen and the contaminant on the catalyst surface where they react to form carbon dioxide, water, and hydrochloric gas. The catalyst enables the oxidation reaction to occur at much lower temperatures than required by a conventional thermal oxidation. VOCs are thermally destroyed at

temperatures typically ranging from 320 to 540 ?C (600 to 1,000 ?F) by using a solid catalyst. First, the contaminated air is directly preheated (electrically or, more frequently, using natural gas or propane) to reach a temperature necessary to initiate the catalytic oxidation [310 to 370 ?C (600 to 700 ?F)] of the VOCs. Then the preheated VOC-laden air is passed through a bed of solid catalysts where the VOCs are rapidly oxidized. Thermal oxidizers can often be converted to catalytic units after initially high influent contaminant concentrations decrease to less than 1,000 to 5,000 ppmv.

Catalyst systems used to oxidize VOCs typically use metal oxides such as nickel oxide, copper oxide, manganese dioxide, or chromium oxide. Noble metals such as platinum and palladium may also be used. Most commercially available catalysts are proprietary.

In most cases, the thermal or catalytic oxidation process can be enhanced to reduce auxiliary fuel costs by using an air-to-air heat exchanger to transfer heat from the exhaust gases to the incoming contaminated air. Typically, about 50% of the heat of the exhaust gases is recovered.

Applicability: The target contaminant groups for oxidation are nonhalogenated VOCs and SVOCs and fuel hydrocarbons. Both precious metal and base metal catalysts have been developed that are reportedly capable of effectively destroying halogenated (including chlorinated) hydrocarbons. Specific chlorinated hydrocarbons that have been treated include TCE, TCA, methylene chloride, and 1,1-DCA.

Limitations: The following factors may limit applicability and effectiveness:

- If sulfur or halogenated compounds or high particulate loadings are in the emissions stream, the catalyst can be poisoned/deactivated and require replacement.
- Destruction of halogenated compounds requires special catalysts, special materials or construction, and the addition of a flue gas scrubber to reduce acid gas emissions.
- Influent gas concentrations must be <25% of the lower explosive limit.
- The presence of chlorinated hydrocarbons (see comment above) and some heavy metals (e.g., lead) may poison a particular catalyst.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.3 (Data Requirements for Air Emissions/Off-Gases). Because of the limitations discussed in the previous section, it is important that the contaminated air stream be well characterized.

Performance Data:

Thermal oxidation is effective for site remediation. Its use is increasing among remediation equipment vendors, and several variations in design are being marketed. Growing applications include treatment of air stripper and vacuum extraction gas-phase emissions.

More than 20 firms manufacture catalytic oxidation systems specifically for remedial activities. These firms will generally supply the equipment to remedial action contractors for integration with specific remedial technologies, such as in situ vapor extraction of organics from soil or air stripping of organics from groundwater.

Despite its relatively newer application in remedial activities, catalytic oxidation is a mature technology, and its status as an implementable technology is well established. Nevertheless, the technology continues to evolve with respect to heat recovery techniques, catalysts to increase destruction efficiency and/or to extend the operating life of the catalyst bed, and performance data on a wider range of VOCs.

Cost:

The primary factors that will impact the overall cost include quantity, concentration, and type of contaminant; required destruction efficiencies; management of residuals; and utility and fuel costs.

Thermal treatment is generally more costly than other remedial technologies but offers the advantage of permanent, efficient contaminant destruction within a relatively short time frame. Equipment costs range from $25,000 for a 200-scfm unit to as much as $200,000 for a 2,000-scfm unit.

Typical energy costs for a catalytic oxidation system alone, operating at 100 to 200 scfm, will range from $8 to $15 per day (for natural gas or propane-fired systems) and $20 to $40 per day (for electrically heated systems). Capital costs of equipment operating at throughputs of 2.8 to 5.6 cubic meters per minute (100 to 500 scfm) are estimated to be in a range from $20,000 to $100,000. If treatability studies, tests, or demonstrations are required, additional costs may include:

- Laboratory treatability studies — $10,000 to $50,000.
- Pilot tests or field demonstrations — $100,000 to $500,000.

References:

Elliott, Captain Michael G., and Captain Edward G. Marchand, 1989. "U.S. Air Force Air Stripping and Emissions Control Research," in *Proceedings of the 14th Annual Army Environmental R&D Symposium,* Williamsburg, VA, USATHAMA Report No. CETHA-TE-TR-90055.

EPA, 1987. *Destruction of Organic Contaminants by Catalytic Oxidation,* EPA/600/D-87/224.

Site Information:

Site Name	Contact	Summary	Beginning Levels	Levels Attained	Costs
Dover AFB	Maj. Mark Smith	Field test of various catalysts in a catalytic oxidation system treating TCE emissions from air strippers	NA	NA	NA
Wurtsmith AFB	NA	Groundwater contaminated with TCE. Air stripping	NA	NA	NA
Former gasoline service station, Santa Monica, CA	NA	Leaking resulted in contamination of soil and groundwater with BTEX. Dual extraction	NA	NA	NA
Los Angeles, CA	NA	SVE treatment of TCE soils	NA	NA	NA

Note: NA = Not Available.

Points of Contact:

Contact	Government Agency	Phone	Location
Leslie Karr	NFESC	(805) 982-1618	Code 411 Port Hueneme, CA 93043
R.L. Biggers	NFESC	(805) 982-2640	Code 414 Port Hueneme, CA 93043
Major Mark Smith	USAF Environics Directorate	(904) 283-6126	AL/EQW Tyndall AFB, FL
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401

4.55 VAPOR-PHASE CARBON ADSORPTION

Description: Vapor-phase carbon adsorption is a remediation technology in which pollutants are removed from air by physical adsorption onto activated carbon grains. Carbon is "activated" for this purpose by processing the carbon to create porous particles with a large internal surface area (300 to 2,500 square meters or 3,200 to 27,000 square feet per gram of carbon) that attracts and adsorbs organic molecules as well as certain metal and inorganic molecules.

4-55 TYPICAL VAPOR-PHASE CARBON ADSORPTION SYSTEM

Commercial grades of activated carbon are available for specific use in vapor-phase applications. The granular form of activated carbon is typically used in packed beds through which the contaminated air flows until the concentration of contaminants in the effluent from the carbon bed exceeds an acceptable level. Granular-activated carbon (GAC) systems typically consist of one or more vessels filled with carbon connected in series and/or parallel operating under atmospheric, negative, or positive pressure. The carbon can then be regenerated in place, regenerated at an off-site regeneration facility, or disposed of, depending upon economic considerations.

Carbon can be used in conjunction with steam reforming. Steam reforming is a technology designed to destroy halogenated solvents (such as carbon tetrachloride, CCl_4, and chloroform, $CHCl_3$) adsorbed on activated carbon by reaction with superheated steam (steam reforming) in a commercial reactor (the Synthetica Detoxifier).

Applicability: Vapor-phase carbon adsorption is not recommended to remove high contaminant concentrations from the effluent air streams. Economics favor pretreatment of the VOC stream, followed by the use of a vapor-phase GAC system as a polishing step.

Limitations: Factors that may limit the effectiveness of this process include:

- Spent carbon transport may require hazardous waste handling.
- Spent carbon must be disposed of and the adsorbed contaminants must be destroyed, often by thermal treatment.
- Relative humidity greater than 50% can reduce carbon capacity.
- Elevated temperatures from SVE pumps (greater than 38 ?C or 100 ?F) inhibit adsorption capacity.
- Biological growth on carbon or high particulate loadings can reduce flow through the bed.
- Some compounds, such as ketones, may cause carbon bed fires because of their high heat release upon adsorption.

Data Needs: A detailed discussion of these data elements is provided in Subsection 2.2.3 (Data Requirements for Air Emissions/Off-Gases).

Factors that affect adsorption are temperature, pH, type, and pore size of the carbon, the type and concentration of the contaminant, residence time in the bed, and, in gas phase adsorption, temperature and humidity. At high temperatures, the volatility of compounds increases, thus reducing their affinity for carbon. Adsorption of organic acids such as benzoic acid generally decreases with increasing pH. Basic compounds are adsorbed better at high pH. Activated carbon is available from manufacturers in a variety of grades with different properties and affinities for adsorption of contaminants. Thus, it is often necessary to conduct adsorption tests with a particular contaminated stream on a variety of activated carbons from several manufacturers to identify a carbon that will be most effective for a particular application.

Performance Data: For gaseous systems, linear bed velocities typically range between 8 and 100 feet per minute, although velocities as high as 200 feet per minute have been used, and residence times range from one tenth of a second to a minute.

If only one or two contaminants are of concern in the wastestream and there is little or no contamination from natural organic materials, a batch isotherm test is usually sufficient to design the system (i.e., determine system size and carbon usage). It is also possible to use historical column test data that are available from vendors for a wide assortment of contaminants to obtain initial design estimates and to corroborate test results. Isotherm tests can also be used to compare different carbons and to investigate the effects of pH and temperature on carbon performance. If the use of regenerated carbon is planned, tests should be performed with regenerated carbon to obtain a more realistic estimate of the average adsorptive capacity that can be expected

during operation. Regenerated carbon costs less but tends to have a lower adsorptive capacity than virgin carbon.

Cost: Equipment costs range from less than $1,000 for a 100-scfm unit to $40,000 for a 7,000-scfm unit. Carbon cost is $2 to $3 per pound.

References:

EPA, 1991. *Granular Activated Carbon Treatment*, Engineering Bulletin, EPA, OERR, Washington, DC, EPA/540/2-91/024.

Hinshaw, G.D., C.B. Fanska, D.E. Fiscus, and S.A. Sorensen, Midwest Research Institute, Undated. *Granular Activated Carbon (GAC) System Performance Capabilities and Optimization, Final Report*, USAEC, APG, MD, MRI Project No. 81812-S, Report No. AMXTH-TE-CR87111. Available from NTIS, Springfield, VA, Order No. ADA179828.

Points of Contact:

Contact	Government Agency	Phone	Location
Beth Fleming	USAE-WES	(601) 634-3943	3909 Halls Ferry Road Vicksburg, MS 39180-6199
Ron Turner	EPA RREL	(513) 569-7775	26 West M.L. King Dr. Cincinnati, OH 45268
Technology Demonstration and Transfer Branch	USAEC	(410) 671-2054 Fax: (410) 612-6836	SFIM-AEC-ETD APG, MD 21010-5401
David Biancosino Program Manager	DOE	(301) 903-7961	EM-551, Trevion II Washington, DC 20585

Section 5
REFERENCES

This reference section has been divided into three subsections:

- 5.1 Document Sources
- 5.2 Listing by Topic
  - 5.2.1 International Surveys and Conferences
  - 5.2.2 Technology Survey Reports
  - 5.2.3 Treatability Studies (General)
  - 5.2.4 Groundwater
  - 5.2.5 Thermal Processes
  - 5.2.6 Biological
  - 5.2.7 Physical/Chemical
  - 5.2.8 Community Relations
- 5.3 Listing by Author

Subsection 5.1 contains points of contact and agencies for obtaining the documents presented in this section. Subsection 5.2 lists the documents presented in the *Federal Publications on Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation*, FRTR, 1993. These documents address innovative technologies and are sorted by topic and by publishing agency. Subsection 5.3 presents a complete listing of all published references excerpted from each source document to this guide. This subsection has been sorted by author and date of publication.

✍ 5.1 DOCUMENT SOURCES

EPA documents and reports listed in this bibliography may be obtained from the following sources:

EPA scientific and technical reports: Center for Environmental Research Information (CERI)	CERI 26 West M.L. King Drive Cincinnati, OH 45268 (513) 569-7562 FAX (513) 569-7566
EPA/530 Document Numbers: RCRA Docket and Information Center	EPA Attn: RCRA Information Center 401 M Street, SW, WH-562 Washington, DC 20460 (202) 260-9327
EPA Document Numbers (except EPA/530): National Center for Environmental Publications and Information (NCEPI)	NCEPI 11029 Kenwood Road Cincinnati, OH 45242 FAX OrdeGs: (513) 891-6685

OSWER Directives:
Superfund Document Center

EPA/Document Center
401 M Street SW, OS-245
Washington, DC 20460
Attn. Superfund Directives
(202) 260-9760

Publications from
EPA/Ada Laboratory:

Kay Cooper
EPA/RSKERL
P.O. Box 1198
Ada, OK 74820
(405) 436-8651

NTIS Document Numbers:

(Non-EPA personnel must order EPA documents with NTIS numbers from NTIS.)

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

To order reports: (703) 487-4650

For general information: (703) 487-4600

Order U.S. Air Force materials not available from NTIS from:

U.S. Air Force Center for Environmental Excellence
AFCEE/CC
Brooks Air Force Base, TX 78235-5000
(210) 536-1110

Order U.S. Army documents from NTIS (see above) or DTIC:

Defense Technical Information Center (DTIC)
Cameron Station
Alexandria, VA 22304-6145

User Services: (703) 274-3848

Documents with CETHA or AMXTH numbers, not available through NTIS or DTIC, may be requested from:

U.S. Army Environmental Center
ATTN: SFIM-AEC-ETD
Aberdeen Proving Ground, Maryland 21010-5401
(410) 671-2054

Documents with WES numbers, not available from NTIS, may be requested from:

Environmental Engineering Division
U.S. Army Corps of Engineers Waterways Experiment Station
Vicksburg, MS 39180-6199
(601) 643-2856

Order U.S. Department of Energy documents with OSTI Numbers from:

OSTI
U.S. DOE
Oak Ridge, TN 37801

U.S. Department of the Interior documents may be ordered from the Library of the Salt Lake City Research Center:

Library
Salt Lake City Research Center
U.S. Department of Interior
729 Arapeen Drive
Salt Lake City, UT 84108
(801) 524-6112

Naval Facilities Engineering Services Center (formerly NCEL and/or NEESA) documents that are not available through NTIS may be requested from the laboratory directly:

Division Director
Code 411
560 Center Drive
Naval Facilities Engineering Service Center
Port Hueneme, CA 93043-4328

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✍ 5.2 LISTING BY TOPIC

This bibliography addresses technologies that provide for the treatment of hazardous wastes; therefore, it does not contain information or references for containment or other nontreatment strategies, such as landfilling and capping. This bibliography emphasizes innovative technologies for which detailed cost and performance data are not readily available. Information on more conventional treatment technologies, such as incineration and solidification, is not included.

In addition to improving access to information on innovative technologies, the FRTR 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 as a starting point in pursuit of information on innovative alternative hazardous waste treatment technologies and should not be considered all-inclusive.

✍ 5.2.1 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, (Abstract Proceedings).
(First Forum, Atlanta, GA), EPA/540/2-89/055; NTIS: PB90-268509
(Second Forum, Philadelphia, PA), EPA/540/2-90/009; NTIS: PB91-145649
(Third Forum, Dallas, TX), EPA/540/2-91/016; NTIS: PB92-233881
(Fourth Forum, San Francisco, CA), EPA/540/R-92/081

NATO/CCMS Project — International Evaluation of In Situ Biorestoration of Contaminated Soil and Groundwater.
EPA/540/2-90/012

NATO/CCMS Project — Demonstration of Remedial Action Technologies for Contaminated Land and Ground Water.
Proceedings are maintained in the Hazardous Waste Collection, EPA Headquarters Library, Washington, DC

Proceedings of the Symposium on Soil Venting.
EPA/600/R-92/174; NTIS: PB93-122323

Remedial Action, Treatment, and Disposal of Hazardous Waste: Proceedings of the 18th Annual RREL Hazardous Waste Research Symposium.
EPA/600/R-92/028; NTIS: PB92-166859

Residual Radioactivity and Recycling Criteria: Workshop Proceedings.
EPA 520/1-90/013; NTIS: PB91-179119

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.
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Appendix A VISITT

EPA publishes the Vendor Information System for Innovative Treatment Technologies (VISITT). This data base has been developed by the Technology Innovation Office (TIO) in the Office of Solid Waste and Emergency Response (OSWER) as part of a broad effort to promote the use of innovative treatment technologies for the cleanup of soil and groundwater contaminated by hazardous and petroleum waste. VISITT is designed to capture current information on the availability, performance, and cost of innovative treatment to remediate contaminated waste sites.

VISITT provides environmental professionals with rapid access to up-to-date information on innovative technologies and the companies that offer them. VISITT's menu-driven design allows the user to search the extensive technology information for particular applications and technology types. The user, for example, can enter a waste description to identify innovative technologies in the system that treat such wastes. The user can also locate specific sites where vendors may have conducted treatability studies or cleanups.

Once the data base identifies the technologies and vendors meeting the user's requirements, the user can then review such information as available equipment, performance data, and experience. Printing options include printing all of the technology information for a given vendor, or only those data fields of particular interest.

The basic information on each technology includes the vendor name, address, and phone number; technology description; highlights; limitations; and the contaminant and waste/media treated. Many of the vendors with technologies at the pilot and full scale also provide a summary of performance data, project names and contacts, available hardware and capacity, unit price information, treatability study capabilities, and literature references. Performance data, project information, and literature citations can be used to substantiate a vendor's claims.

The third revision of the data base, VISITT 3.0, is offered on four 5¼-inch or three 3½-inch floppy disks, accompanied by a user manual. The data base requires a personal computer with at least 640K of RAM (random access memory), an operating system of DOS Version 3.3 or higher (that is, IBM or IBM-compatible), and 10 megabytes of hard disk storage. VISITT is not offered for Apple Macintosh format. The data base is compiled and requires no other software to operate. VISITT is compatible with most printers and local area networks (LANs). EPA, through PRC Environmental Management, Inc., offers technical assistance to correct any hardware or software problems associated with installing or using VISITT.

3.0 is also available as a downloadable file (VISITT 3.2ip) on EPA's Cleanup Information Bulletin Board System (CLU-IN). For a list of files on the CLU-IN, type <F7 for file directories, and choose the directory for data bases. To access CLU-IN by modem, call (301) 589-8366, or contact the CLU-IN Help Desk at (301) 589-8368.

VISITT 3.0 is available at no charge. To order the VISITT diskettes and user manual, and to become a registered user, fill out and mail the order/registration form provided to EPA/NCEPI, P.O. Box 42419, Cincinnati, OH 45242-0419; FAX, (513) 891-6685; verification, (513) 891-6561. Please provide all of the required information; EPA cannot process incomplete forms. Registration ensures that you will receive information on subsequent corrections and updates to the system.

The VISITT hotline and software support are provided by PRC Environmental Management, Inc., for the Technology Innovation Office under Contract No. 68-CO-0047. Linda Fiedler is the EPA project manager.

ORDERING VISITT 3.0

To order the VISITT 3.0 diskettes and user manual, and to become a registered user, please complete this order and registration form and mail or fax it to the location indicated below. VISITT 3.0 is available at NO CHARGE. VISITT 3.0 also is available on EPA's CLU-IN Bulletin Board.

IMPORTANT: All registered users of version 1.0 and 2.0 should complete this form and mail or fax it to the location indicated below.

Special Note to EPA Staff: TIO is working directly with EPA Headquarters and Regional offices, EPA laboratories, and EPA libraries to install VISITT on LANs and at workstations. For more information, contact the OSWER Technology Innovation Office.

EPA Vendor Information Systemfor Innovative Treatment Technologies (VISITT) Version 3.0 Order and Registration Form

Mail to: U.S. EPA/NCEPI
P.O. Box 42419
Cincinnati, OH 45242-0419

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FAX to: U.S. EPA/NCEPI
(513) 891-6685
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Please type or print legibly. Allow 3 to 4 weeks for delivery.

Name: _____

Company/Agency _____

Street _____

City _____ State _____

Country _____ Telephone Number _____

Date Ordered _____

_____ Register me as a VISITT user.

_____ Send me VISITT 3.0 diskettes and a user manual.

Diskette size (check one) 3½ _ 5¼ _____

_____ Send me a VISITT 3.0 user manual *only*.

_____ I am an innovative treatment technology vendor and would like to receive an application to be included in VISITT 4.0. Place me on the VISITT 4.0 Application Mailing List.

_____ I am an innovative measurement or monitoring technology vendor and would like to receive an application for the new measurement and monitoring vendor data base. Place me on the Measurement/Monitoring Data base

Application Mailing List.

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LIST OF VENDORS BY TECHNOLOGY

Inclusion in EPA's Vendor Information System for Innovative Treatment Technologies (VISITT) does not mean that EPA approves, recommends, licenses, certifies, or authorizes the use of any of the technologies. Nor does EPA certify the accuracy of the data. This listing means only that the vendor has provided information on a technology that EPA considers to be eligible for inclusion in this data base.

AIR EMISSIONS/OFF GAS TREATMENT

OFF-GAS TREATMENT

BECO Engineering, Co.	(412) 828-6080
Bohn Biofilter Corporation	(602) 621-7225
Compact Membrane Systems, Inc.	(302) 984-1762
Ecology Technologies International, Inc.	(602) 985-5524
EG&G Corporation	(914) 246-3401
Envirogen, Inc.	(609) 936-9300
General Atomics	(619) 455-2499
IT Corporation	(615) 690-3211
KSE, Inc.	(413) 549-5506
M.L. Energia	(609) 799-7970
Membrane Technology and Research, Inc.	(415) 328-2228
Nucon International, Inc.	(614) 846-5710
Process Technologies, Inc.	(208) 385-0900
Purus, Inc.	(408) 955-1000
TAUW Hilieu	(31-570) 099-911 (the Netherlands)
Zapit Technology, Inc.	(408) 986-1700

BIOLOGICAL TREATMENT

BIOREMEDIATION — IN SITU GROUNDWATER

ABB Environmental Services, Inc.	(617) 245-6606
Chester Environmental	(412) 269-5700
Cognis Inc.	(707) 576-6204
Ecology Technologies International, Inc.	(602) 985-5524
Electrokinetics,Inc.	(504) 388-3992
ENSR Consulting and Engineering	(805) 388-3775
EODT Services, Inc.	(615) 690-6061
ESE Biosciences, Inc.	(919) 872-9686
GAIA Resources, Inc.	(312) 329-0368
Geo-Microbial Technologies, Inc.	(918) 535-2281
Groundwater Technology, Inc.	(510) 671-2387
IT Corporation	(615) 690-3211
Kamron Environmental Services, Inc.	(404) 636-0928
Microbial Environmental Services	(515) 276-3434
OHM Corporation	(419) 424-4932
Remediation Technologies, Inc.	(919) 967-3723
Waste Stream Technology, Inc.	(716) 876-5290
Yellowstone Environmental Science, Inc.	(406) 586-3905

BIOREMEDIATION — IN SITU LAGOON

Ecology Technologies International, Inc.	(602) 985-5524
OHM Corporation	(419) 424-4932
Praxair, Inc. (formerly Union Carbide)	(914) 789-3034

LIST OF VENDORS BY TECHNOLOGY (CONTINUED)

BIOREMEDIATION — IN SITU SOIL

ABB Environmental Services, Inc.	(617) 245-6606
Billings and Associates, Inc.	(505) 345-1116
Biogee International, Inc.	(713) 578-3111
Chester Environmental	(412) 269-5700

Detox Industries	(713) 240-0892
Ecology Technologies International, Inc.	(602) 985-5524
Electrokinetics, Inc.	(504) 388-3992
ESE Biosciences, Inc.	(919) 872-9686
Geo-Microbial Technologies, Inc.	(918) 535-2281
Grace Dearborn, Inc.	(905) 279-2222
Hayward Baker Environmental, Inc.	(410) 551-1995
In-Situ Fixation, Inc.	(602) 821-0409
Kemron Environmental Services	(404) 636-0928
Microbial Environmental Services, Inc.	(515) 276-3434
Quarternary Investigations, Inc. (Q)	(909) 423-0740
SBP Technologies, Inc.	(904) 934-9282
Waste Stream Technologies, Inc.	(716) 876-5290

BIOREMEDIATION — SLURRY PHASE

Biosolutions, Inc.	(201) 616-1158
Biogee International, Inc.	(713) 578-3111
Bogart Environmental Services, Inc.	(615) 754-2847
Cognis, Inc.	(707) 575-7155
Ecology Technologies International, Inc	(602) 985-5524
Elmco Process Equipment Co.	(801) 526-2082
EODT Services, Inc.	(615) 690-6061
Geo-Microbial Technologies, Inc.	(918) 535-2281
IT Corporation	(615) 690-3211
OHM Corporation	(419) 424-4932
Praxair, Inc. (formerly Union Carbide)	(914) 789-3034
Remediation Technologies, Inc.	(602) 577-8323
SBP Technologies, Inc.	(904) 934-9282
Waste Stream Technologies, Inc.	(716) 876-5290
Yellowstone Environmental Science, Inc.	(406) 586-3905

BIOREMEDIATION — SOLID PHASE

ABB Environmental Services, Inc.	(617) 245-6606
Alvarez Brothers	(512) 576-0404
Arctech, Inc.	(703) 222-0280
Biogee International, Inc.	(713) 578-3111
Bioremediation Services, Inc.	(503) 624-9464
Chester Environmental	(412) 269-5700
Clean-up Technology, Inc.	(310) 828-4844
Cognis, Inc.	(707) 575-7155
Earthfax Engineering, Inc.	(801) 561-1555
Ecology Technologies International, Inc.	(602) 985-5524
ENSR Consulting and Engineering	(508) 635-9500
Environmental Tech. of North America, Inc.	(919) 299-9998
ETUS, Inc.	(407) 321-7910
Geo-Microbial Technologies, Inc.	(918) 535-2281
Grace Dearborn, Inc.	(905) 279-2222
Groundwater Technology, Inc.	(510) 671-2387
IT Corporation	(615) 690-3211
Microbial Environmental Services, Inc.	(515) 276-3434
Mycotech Corporation	(406) 782-2386
OHM Corporation	(419) 424-4932
Remediation Technologies, Inc.	(602) 577-8323
SBP Technologies, Inc.	(904) 934-9282
Waste Stream Technology, Inc.	(716) 876-5290

LIST OF VENDORS BY TECHNOLOGY (CONTINUED)

BIOREMEDIATION — NOT OTHERWISE SPECIFIED

B&S Research, Inc.	(218) 984-3757
Bioremediation Services, Inc.	(503) 624-9464
Bioremediation Technology Services, Inc.	(209) 984-4963
Chempete, Inc.	(708) 365-2007
Clyde Engineering Services	(504) 362-7929
Detox Industries, Inc.	(713) 240-0892
Eco-Tec, Inc./Ecology Technology	(206) 392-0304

EPG/Haecon, Inc.	(708) 381-0020
Sybron Chemicals	(609) 893-1100
ETUS Inc.	(407) 321-7910

BIOVENTING

ABB Environmental Services, Inc.	(617) 245-6606
Battelle Pacific Northwest Laboratories	(509) 372-2273
Engineering Sciences, Inc.	(303) 831-8100
ENSR Consulting and Engineering	(508) 635-9500
Environeering	(419) 885-3155
H2O Science, Inc.	(714) 379-1157
Hayward Baker Environmental, Inc.	(410) 551-1995
IT Corporation	(615) 690-3211
Mittlehauser Corporation	(714) 472-2444
OHM Corporation	(419) 424-4932
Quanternary Investigations, Inc. (QI)	(909) 423-0740
Terra Vac, Inc.	(714) 252-8900
Vapex Environmental Technologies, Inc.	(617) 821-5560

PHYSICAL/CHEMICAL TREATMENT

ACID EXTRACTION

Center for Hazardous Materials Research	(412) 826-5320
Cognis, Inc.	(707) 575-7155
Earth Treatment Technologies	(610) 497-6729
IT Corporation	(615) 690-3211
Lockheed Corporation	(702) 897-3626

ADSORPTION/ABSORPTION — IN SITU

Dynaphore, Inc.	(804) 672-3464
Environmental Fuel Systems, Inc.	(210) 796-7767

AIR SPARGING — IN SITU GROUNDWATER

Billings & Associates, Inc.	(505) 345-1116
Hayward Baker Environmental Inc.	(410) 551-1995
Horizontal Technologies	(813) 995-8777
IEG Technologies Corporation	(704) 357-6090
IT Corporation	(615) 690-3211
Quarternary Investigations, Inc. (Q)	(909) 423-0740
Terra Vac Inc.	(714) 252-8900
Vapex Environmental Technologies, Inc.	(617) 821-5560

CHEMICAL TREATMENT — IN SITU GROUNDWATER

Environmental Technologies, Inc.	(519) 824-0432
Geochem Division of Terra Vac	(303) 988-8902
Intera, Inc.	(512) 346-2000

LIST OF VENDORS BY TECHNOLOGY (CONTINUED)

CHEMICAL TREATMENT — OTHER

Cleantech of Arkansas, Inc.	(501) 834-7600
Davy Research and Development Ltd.	(44-692) 607-108 (UK)
Environmental Scientific, Inc. (ESI)	(919) 941-0847
EPS Environmental, Inc.	(201) 368-7902
Integrated Chemistries, Inc.	(612) 636-2380
Viking Industries	(615) 890-1018

DECHLORINATION

A.L. Sandpiper Corporation	(614) 486-0405
SDTX Technologies, Inc.	(518) 734-4483

DELIVERY/EXTRACTION SYSTEMS

Drilex Systems, Inc.	(713) 937-8888
Eastman Charrington Environmental	(713) 722-7777
Horizontal Technologies, Inc.	(813) 995-8777
Millgard Environmental Corporation	(313) 261-9760
Novaterra, Inc.	(310) 843-3190

DUAL-PHASE EXTRACTION

Billings & Associates	(505) 345-1116
Dames & Moore	(215) 657-7134
First Environment, Inc.	(201) 616-9700
IT Corporation	(615) 690-3211
Terra Vac, Inc.	(714) 252-8900
Vapex Environmental Technologies, Inc.	(617) 821-5560

MAGNETIC SEPARATION

S.G. Frantz Co., Inc.	(609) 882-7100

MATERIALS HANDLING/PHYSICAL SEPARATION

Canonie Environmental Services Corporation	(303) 790-1747
Ecova Corporation	(303) 279-9712
Microfluidics Corporation	(617) 969-5452
Onsite * Offsite Inc./Battelle PNL	(818) 303-2229
Portec, Inc.	(605) 665-8770
Recra Environmental, Inc.	(716) 691-2600

OXIDATION/REDUCTION

Arctech, Inc.	(703) 222-0280
Eli Eco Logic International, Inc.	(519) 856-9591
EM&C Engineering Associates	(714) 957-6429
ETUS, Inc.	(407) 321-7910
G.E.M., Inc.	(501) 337-9410
High Voltage Environmental Applications	(305) 593-5330
IT Corporation	(615) 690-3217
R & M Technologies, Inc.	(800) 699-7227
Synthetica Technologies, Inc.	(510) 525-3000

PNEUMATIC FRACTURING

Accutech Remedial Systems, Inc.	(908) 739-6444
Terra Vac, Inc.	(714) 252-8900

LIST OF VENDORS BY TECHNOLOGY (CONTINUED)

SOIL FLUSHING — IN SITU

Horizontal Technologies, Inc.	(813) 995-8777
Scientific Ecology Group, Inc.	(412) 247-6255

SOIL VAPOR EXTRACTION

AWD Technologies, Inc.	(301) 948-0040
Geo-Con, Inc.	(412) 856-7700
IT Corporation	(615) 690-3211
Mittlehauser Corporation	(708) 368-0201
Terra Vac, Inc.	(714) 252-8900
Vapex Environmental Technologies, Inc.	(617) 821-5560

SOIL WASHING

Alternative Remedial Technologies, Inc.	(813) 264-3506

B&W Nuclear Environmental Services, Inc.	(804) 948-4610
Benchem	(412) 361-1426
Bergmann USA	(615) 452-5500
Bio-Recovery Systems, Inc.	(505) 523-0405
Biotrol, Inc.	(612) 942-8032
Canonie Environmental Services Corp.	(303) 790-1747
Divesco, Inc.	(601) 932-1934
Earth Decontaminators, Inc.	(714) 262-2290
Geochem Division of Terra Vac	(303) 988-8902
Lockheed Corporation	(702) 897-3626
Nukem Development	(713) 520-9494
OHM Corporation	(510) 256-6100
On-Site Technologies, Inc.	(408) 371-4810
Scientific Ecology Group, Inc.	(412) 247-6255
Turboscope Velco Environmental Service	(713) 799-5289
Warren Spring Laboratory	(44-438) 74-122 (UK)
West Pac Environmental, Inc.	(206) 762-1190
Westinghouse Remediation Services, Inc.	(404) 299-4736

SOLIDIFICATION/STABILIZATION

Chemfix Technologies, Inc.	(504) 461-0466
Funderburk & Associates	(903) 545-2004
International Waste Technologies	(316) 269-2660
Geo-Con, Inc.	(412) 856-7700
Silicate Technology Corporation	(602) 948-7100
Soliditech, Inc.	(713) 497-8558
WASTETECH, Inc.	(615) 483-6515
S.M.W. Seiko, Inc.	(510) 783-4105
Separation and Recovery Systems, Inc.	(714) 261-8860
Wheelabrator Technologies, Inc.	(603) 929-3000

SOLVENT EXTRACTION

Art International, Inc.	(201) 627-7601
CF Systems Corporation	(617) 937-0800
Dehydro-Tech Corporation	(201) 887-2182
EM&C Engineering Associates	(714) 957-6429
Envirogen, Inc.	(609) 936-9300
Geo-Microbial Technologies, Inc.	(918) 535-2281
Integrated Chemistries, Inc.	(612) 636-2380
Nukem Development	(713) 520-9494
Resources Conservation Co.	(301) 596-6066
SRE, Inc.	(201) 661-5192
Terra-Kleen Corporation	(405) 728-0001

LIST OF VENDORS BY TECHNOLOGY (CONTINUED)

THERMAL TREATMENT

ELECTRICAL SEPARATION

Electro-Petroleum, Inc.	(610) 687-9070
Electrokinetics, Inc.	(504) 388-3992
Water and Slurry Purification Process	(303) 650-5674

ELECTRO-THERMAL GASIFICATION — IN SITU

Bio-Electrics, Inc.	(816) 474-4895

INCINERATION

Alberta Special Waste Treatment Centre	(403) 333-4197
Allied-Signal Tar Products	(205) 787-8605
Aptus	(801) 531-4273
BDT, Inc.	(716) 759-2868
Chemical Waste Management, Inc.	(800) 541-5511
Environmental Systems Co. (ENSCO)	(800) 349-7407
L.W.D, Inc.	(502) 395-8813

Laidlaw Environmental Services	(800) 922-3309
Rhone-Poulenc Basic Chemicals Co.	(713) 688-9311
Rollins Environmental Services, Inc.	(609) 342-7051
Ross Incineration Services, Inc.	(216) 748-2171
Thermall KEM, Inc.	(803) 324-5310
Trade Waste Incineration	(618) 271-2804
WESTON, Inc.	(610) 701-7423
Waste Technologies Industries	(216) 385-7337

PYROLYSIS

Bio-Electrics, Inc.	(816) 474-4895
Product Control Ltd- E. Someus	(44-481) 726-426 (UK)

SLAGGING OFF-GAS TREATED

Horsehead Resource Development Co., Inc.	(412) 773-2289

THERMAL DESORPTION

Advanced Soil Technologies	(612) 486-7000
Ariel Industries, Inc.	(615) 894-1957
Canonie Environmental Services Corp.	(219) 926-8651
Carlo Environmental Technologies, Inc.	(810) 468-9580
Carson Environmental	(310) 478-0792
Clean Berkshires, Inc.	(617) 695-9770
Clean-Up Technology, Inc.	(310) 828-4844
Contamination Technologies, Inc.	(617) 575-8920
Conteck Environmental Services, Inc.	(612) 441-4965
Covenant Environmental Technologies, Inc.	(901) 759-5874
DBA, Inc.	(510) 447-4711
Ecova Corporation	(303) 279-9712
Enviro-Klean Soils, Inc.	(206) 888-9388
Hazen Research, Inc.	(303) 279-4501
Hrubetz Environmental Services, Inc.	(214) 363-7833
IT Corporation	(615) 690-3211
Kalkaska Construction Service, Inc.	(616) 258-9134
OBG Technical Services, Inc.	(315) 437-6400
Pet-Con Soil Remediation, Inc.	(608) 588-7365
Pittsburgh Mineral & Environmental Technologies	(412) 843-5000
Recycling Science International, Inc.	(312) 357-1448

LIST OF VENDORS BY TECHNOLOGY (CONTINUED)

THERMAL DESORPTION (Continued)

Remediation Technologies, Inc.	(508) 371-1422
Roy F. Weston, Inc	(610) 701-7423
Rust Remedial Services, Inc.	(803) 646-2413
Seaview Thermal Systems	(215) 654-9800
Separation and Recovery Systems, Inc.	(714) 261-8860
Soil Purification, Inc./ASTEC	(706) 861-0069
Soiltech ATP Systems, Inc.	(303) 790-1747
Southwest Soil Remediation, Inc.	(602) 577-7680
Texarome, Inc.	(210) 232-6079
Thermotech Systems Corporation	(407) 290-6000
Western Research Institute	(307) 721-2443
Westinghouse Remediation Services, Inc.	(404) 299-4721

THERMALLY ENHANCED RECOVERY IN SITU

Battelle Pacific Northwest Laboratories	(509) 376-0554
Bio-Electrics, Inc.	(816) 474-4895
EM&C Engineering Associates	(714) 957-6429
Hrubetz Environmental Services, Inc.	(214) 363-7833

KAI Technologies, Inc.	(617) 932-3328
Novaterra, Inc.	(310) 843-3190
Praxis Environmental Technologies, Inc.	(415) 282-9568
R.E. Wright Associates, Inc. (REWAI)	(717) 944-5501
Sive Services	(510) 820-5449
Thermatrix, Inc.	(408) 944-0220

VITRIFICATION

B&W Nuclear Environmental Services, Inc.	(804) 948-4610
Battelle Pacific Northwest Laboratories	(509) 376-6576
Bio-Electrics, Inc.	(816) 474-4895
EET Corporation	(615) 671-7800
Electro-Pyrolysis, Inc.	(610) 687-9070
EM&C Engineering Associates	(714) 957-6429
Geosafe Corporation	(509) 375-0710
Retech, Inc.	(707) 462-6522
Stir-Melter, Inc.	(419) 536-8828
Texaco Syngas, Inc.	(914) 253-4003
Vortec Corporation	(610) 489-2255

Appendix B
DOE SITE REMEDIATION TECHNOLOGIES BY WASTE CONTAMINANT MATRIX *AND* COMPLETED *SITE* DEMONSTRATION PROGRAM PROJECTS AS OF OCTOBER 1993

The DOE *Technology Catalogue* contains extensive information on technologies used for characterization, monitoring, and remediation. These technologies range from innovative/emerging to proven technologies.

Table B-1 was extracted from the DOE *Technology Catalogue* (Document No. DOE/EM-0138P) to provide a complete listing of the technology information presented in that document. Specific detailed information about each listed technology can be obtained by referring to the DOE *Technology Catalogue* or by calling DOE at 1-800-736-3282 (7EM-DATA)

Table B-2 was reproduced from *Superfund Innovative Technology Evaluation Program, Technology Profiles,* Sixth Edition (Document No. EPA/540/R-93/526). This table provides information on completed SITE Demonstration Programs organized in alphabetical order by developer name. Technology contact names and telephone numbers are also provided in the table.

TABLE B-1
DOE SITE REMEDIATION TECHNOLOGIES BY WASTE CONTAMINANT

Technology	Media	Waste Contaminant	Description	Trea
Metals				
Arc Melter Vitrification	Soil	Toxic metals	Vitrification	
Barriers and Post-Closure Monitoring	Arid soils	Soluble metals	Containment/Treatment	
Biological Destruction of Tank Waste	Supernatants, aqueous streams	Toxic metals	Biosorption	
In Situ Vitrification of Contaminated Soils	Soil	Heavy metals	Destruction/Immobilization	
Polyethylene Encapsulation of Radionuclides and Heavy Metals	Aqueous salt and concentrate, saltcake, sludge, ash, ion exchange resin in tanks	Toxic metals, Cr, Pb, Cd	Encapsulation	
Mixed Waste				
Arc Melter Vitrification	Soil	Mixed waste (TRU)	Vitrification	
Dynamic Underground Stripping of VOCs	Soil, groundwater	Mixed waste	Enhanced Removal	
Fixed Hearth DC Plasma Torch Process	Soil, stored waste	Mixed waste	Waste Form Enhancement	
In Situ Vitrification of Contaminated Soils	Soil	Mixed waste	Immobilization	
Organics				
Arc Melter Vitrification	Soil	Organics	Vitrification	
Barriers and Post-Closure Monitoring	Arid soils	VOCs, organics	Containment/Treatment	
Biological Destruction of Tank Waste	Supernatants, aqueous streams	Organics	Biosorption	

TABLE B-1
DOE SITE REMEDIATION TECHNOLOGIES BY WASTE CONTAMINANT (Continued)

Technology	Media	Waste Contaminant	Description	Trea
Organics (Continued)				
Dynamic Underground Stripping of VOCs	Soil, groundwater	VOCs	Enhanced Removal	
Fixed-Hearth DC Plasma Torch Process	Soil, stored waste	Organics	Waste Form Enhancement	
High-Energy Corona	Gas, aqueous and non-aqueous liquids	VOCs, halogenated solvents, TCE, PCE, carbon tetrachloride, chloroform, diesel fuel, gasoline	Destruction	
In Situ Air Stripping	Permeable soils, groundwater	VOCs, light hydrocarbons, chlorinated solvents, TCE, PCE	Enhanced Removal	
In Situ Vitrification of Contaminated Soils	Soil	VOCs	Destruction/Immobilization	
Methane-Enhanced Bioremediation for the Destruction of TCE	Soil, groundwater	Halogenated aliphatic organics, TCA, TCE, PCE	Cometabolic Destruction	
Six-Phase Soil Heating	Soil	VOCs, SVOCs	Extraction	
Steam Reforming	Off-gas of soil	Halogenated solvents, carbon tetrachloride, chloroform adsorbed on granular-activated carbon beds	Destruction	
Thermal Enhanced Vapor Extraction System	Arid soils	VOCs, SVOCs, VOC-oil mixtures, chemicals with vapor pressures <0.0002 atm @ 20 ?C	Extraction	
VOC Off-Gas Membrane Separation	Gas stream	VOCs, halogenated solvents, carbon tetrachloride, chloroform	Membrane Separation	

TABLE B-1
DOE SITE REMEDIATION TECHNOLOGIES BY WASTE CONTAMINANT (Continued)

Technology	Media	Waste Contaminant	Description	Trea
Radioactive				
Biological Destruction of Tank Waste	Supernatant aqueous streams	Various radionuclides, TRU	Separation Volume Reduction	
Compact Processing Units for Radioactive Waste Treatment	Liquids, sludges, slurries	High-level, low-level, TRU	Biosorption	
Cryogenic Retrieval of Buried Waste	Soil	TRU	Freezing/Retrieval Containment	
In Situ Vitrification of Contaminated Soils	Soil	Various radionuclides, TRU	Immobilization	
Polyethylene Encapsulation of Radionuclides and Heavy Metals	Aqueous salt and concentrate, saltcake, sludge, ash, ion exchange resin in tanks	Various radionuclides, TRU	Encapsulation	
Resorcinol-Formaldehyde Ion Exchange Resin for Cesium Removal	Cs supernatant salt streams	Cs	Ion Exchange	
Other or Waste Independent				
Biological Destruction of Tank Wastes	Supernatants, aqueous streams	Nitrate	Separation Volume Reduction	
Cryogenic Retrieval of Buried Waste	Soil, buried waste	Hazardous waste	Freezing/Containment	
Decision Support System To Select Migration Barrier Cover Systems	Arid and humid soils	N/A	Multi-objective Decision Making Software System	
Dynamic Underground Stripping of VOCs	Soil, groundwater	NAPLs, DNAPLs	Enhanced Removal	
Fixed-Hearth DC Plasma Torch Process	Soil, stored waste	Wide variety of solid and liquid wastes, inorganics	Waste Form Enhancement	

TABLE B-1
DOE SITE REMEDIATION TECHNOLOGIES BY WASTE CONTAMINANT (Continued)

Technology	Media	Waste Contaminant	Description	Trea
Other or Waste Independent (continued)				
High-Pressure Waterjet Dislodging and Conveyance End Effector Using Confined Sluicing	Supernatant, sludge, saltcake in tanks	N/A	Confined Sluicing	
Hydraulic Impact End Effector	Hard waste forms in tanks	N/A	Fracturing	
Remote Excavation System	Soil	Buried waste	Retrieval	

COMPLETED *SITE* DEMONSTRATION PROGRAM PROJECTS

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Ino
Accutech Remedial Systems, Inc. Keyport, NJ (005)[a] *Demonstration Date:* July - August 1992	Pneumatic Fracturing Extraction and Catalytic Oxidation/New Jersey Environmental Cleanup Responsibility Act (ECRA) site in Hillsborough, NJ	Harry Moscatello 908-739-6444	Uwe Frank 908-321-6626	Soil, Rock	Not Applic
American Combustion, Inc. Norcross, GA (001) *Demonstration Date:* November 1987- January 1988	PYRETRON® Thermal Destruction/EPA's Incineration Research Facility in Jefferson, AK, using soil from Stringfellow Acid Pit Superfund Site in Glen Avon, CA	Gregory Gitman 404-564-4180	Laurel Staley 513-569-7863	Soil, Sludge, Solid Waste	Not Applic
AWD Technologies, Inc. San Francisco, CA (004) *Demonstration Date:* September 1990	Integrated Vapor Extraction and Steam Vacuum Stripping/San Fernando Valley Groundwater Basin Superfund Site in Burbank, CA	David Bluestein 415-227-0822	Gordon Evans 513-569-7684	Groundwater, Soil	Not Applic
Babcock & Wilcox Co.[b] Alliance, OH (006) *Demonstration Date:* November 1991	Cyclone Furnace/Developer's Facility in Alliance, OH	Lawrence King 216-829-7576	Laurel Staley 513-569-7863	Solids, Soil, Sludges	Nonspecif Radionucl
Bergmann USA Gallatin, TN (007) *Demonstration Date:* May 1992	Soil and Sediment Washing/ Saginaw Bay Confined Disposal Facility in Saginaw, MI	Richard Traver 615-230-2217	Jack Hubbard 513-569-7507	Sediment, Soil	Heavy Me
BioGenesis Enterprises, Inc. Des Plaines, IL (005) *Demonstration Date:* November 1992	BioGenesis_ Soil Washing Process/Refinery site in Minnesota	Charles Wilde 703-250-3442 Mohsen Amiran 708-827-0024	Annette Gatchett 513-569-7697	Soil	Not Applic
Bio-Rem, Inc. Butler, IN (007) *Demonstration Date:* May 1992 - June 1993	Augmented In Situ Subsurface Bioremediation Process/ Williams AFB in Phoenix, AZ	David O. Mann 219-868-5823 800-428-4626	Kim Lisa Kreiton 513-569-7328	Soil, Water	Not Applic

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TABLE B-2
COMPLETED *SITE* DEMONSTRATION PROGRAM PROJECTS AS OF OCTOBER 1993 (Continued)

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Inc
BioTrol, Inc. Eden Prairie, MN (003) *Demonstration Date:* July - September 1989	Biological Aqueous Treatment System/MacGillis and Gibbs Superfund Site in New Brighton, MN	Dennis Chilcote 612-942-8032	Mary Stinson 908-321-6683	Liquid Waste, Groundwater	Nitrates
BioTrol, Inc. Eden Prairie, MN (003) *Demonstration Date:* September - October 1989	Soil Washing System/MacGillis and Gibbs Superfund Site in New Brighton, MN	Dennis Chilcote 612-942-8032	Mary Stinson 908-321-6683	Soil	Metals
Brice Environmental Services Corporation Fairbanks, AK (007) *Demonstration Date:* September 1992	Soil Washing Plant/Alaskan Battery Enterprises Superfund Site in Fairbanks, AK	Craig Jones 907-452-2512	Hugh Masters 908-321-6678	Soil	Radioacti Metals
Canonie Environmental Services Corporation Porter, IN (007) *Demonstration Date:* September 1992	Low Temperature Thermal Aeration (LTTA)/Pesticide Site in Phoenix, AZ	Chetan Trivedi 219-926-7169	Paul dePercin 513-569-7797	Soil, Sediment, Sludge	Not Applic
CeTech Resources, Inc. (A Subsidiary of Chemfix Technologies, Inc.) St. Rose, LA (002) *Demonstration Date:* March 1989	Solidification and Stabilization/Portable Equipment Salvage Company in Clackamas, OR	Sam Pizzitola 504-461-0466	Edwin Barth 513-569-7669	Soil, Sludge, Solids, Ash, Electroplating Wastes	Heavy Me
CF Systems Corporation Woburn, MA (002) *Demonstration Date:* September 1988	Solvent Extraction/New Bedford Harbor Superfund Site in New Bedford, MA	Chris Shallice 617-937-0800	Laurel Staley 513-569-7863	Soil, Sludge, Wastewater	Not Applic

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TABLE B-2
COMPLETED *SITE* DEMONSTRATION PROGRAM PROJECTS AS OF OCTOBER 1993 (Continued)

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Inc
Chemical Waste Management,Inc. Schaumburg, IL (005) *Demonstration Date:* September 1992	PO*WW*ER? Technology/ Developer's Facility in Lake Charles, LA	Annamarie Connolly 708-706-6900	Randy Parker 513-569-7271	Wastewater, Leachate, Groundwater	Metals, Vo Inorganic Salts, Rad
Chemical Waste Management,Inc. Anderson, SC (003) *Demonstration Date:* May 1992	X*TRAX? Thermal Desorption/ Re-Solve, Inc., Superfund Site in North Dartmouth, MA	Carl Palmer 803-646-2413	Paul dePercin 513-569-7797	Soil, Sludge, Other Solids	Not Applic
Dehydro-Tech Corporation East Hanover, NJ (004) *Demonstration Date:* August 1991	Carver-Greenfield Process® for Solvent Extraction of Oily Waste/EPA Research Facility in Edison, NJ	Theodore Trowbridge 201-887-2182	Laurel Staley 513-569-7863	Soil, Sludge, Sediments	Not Applic
E.I. DuPont de Nemours and Co. and Oberlin Filter Co. Newark, DE and Waukesha, WI (003) *Demonstration Date:* April - May 1990	Membrane Microfiltration/ Palmerton Zinc Superfund Site in Palmerton, PA	Ernest Mayer 302-366-3652	John Martin 513-569-7758	Groundwater, Leachate, Wastewater, Electroplating Rinsewaters	Heavy Me Uranium
ECOVA Corporation Golden, CO (006) *Demonstration Date:* May - September 1991	Bioslurry Reactor/EPA Test and Evaluation Facility in Cincinnati, OH	William Mahaffey 303-273-7177	Ronald Lewis 513-569-7856	Soil	Not Applic
ELI Eco Logic International, Inc. Rockwood, Ontario, Canada (006) *Demonstration Date:* October - November 1992	Gas-Phase Chemical Reduction Process/Middleground Landfill in Bay City, MI	Jim Nash 519-856-9591	Gordon Evans 513-569-7684	Soil, Sludge, Liquids, Gases	Not Applic
ELI Eco Logic International, Inc. Rockwood, Ontario, Canada (006) *Demonstration Date:* October - November 1992	Thermal Desorption Unit/ Middleground Landfill in Bay City MI	Jim Nash 519-856-9591	Gordon Evans 513-569-7684	Soil, Sludge, Liquids, Gases	Not Applic
EPOC Water, Inc. Fresno, CA (004) *Demonstration Date:* May 1992	Precipitation, Microfiltration, and Sludge Dewatering/Iron Mountain Superfund Site in Redding, CA	Gary Bartman 209-291-8144	Jack Hubbard 513-569-7507	Sludge, Wastewater, Leachable Soil	Heavy Me

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TABLE B-2
COMPLETED *SITE* DEMONSTRATION PROGRAM PROJECTS AS OF OCTOBER 1993 (Continued)

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Inc
Filter Flow Technology, Inc. League City, TX (006) *Demonstration Date:* September 1993	Heavy Metals and Radionuclide Polishing Filter/Rocky Flats Plant in Golden, CO	Tod Johnson 713-334-6080	Annette Gatchett 513-569-7697	Groundwater, Industrial Wastewater	Heavy Me Radionucl
Funderburk & Associates (formerly HAZCON, Inc.) Oakwood, TX (001) *Demonstration Date:* October 1987	Dechlorination and Immobilization/Former Oil Processing Plant in Douglassville, PA	Ray Funderburk 903-545-2004	Paul dePercin 513-569-7797	Soil, Sludge, Sediments	Heavy Me
General Atomics (formerly Ogden Environmental Services) San Diego, CA (001) *Demonstration Date:* March 1989	Circulating Bed Combustor/Ogden's Facility in La Jolla, CA, using waste from McColl Superfund Site in Fullerton, CA	Jeffrey Broido 619-455-4495	Douglas Grosse 513-569-7844	Soil, Sludge, Slurry, Liquids	Metals, Cy
GIS/Solutions, Inc. Concord, CA (007) *Demonstration Date:* August 1993	GIS/Key? Environmental Data Management Software/San Francisco, CA	Asad Al-Malazi 510-827-5400	Dick Eilers 513-569-7809	Not Applicable	Not Applic
Gruppo Italimpresse (developed by Shirco Infrared Systems, Inc.) Rome, Italy (001) (2 Demonstrations) *Demonstration Dates:* Florida: August 1987 Michigan: November 1987	Infrared Thermal Destruction/Peak Oil Superfund Site in Brandon, FL, and Rose Township Superfund Site in Oakland County, MI	Rome 011-39-06-8802001 Padova 011-39-049-773490	Laurel Staley 513-569-7863	Soil, Sediment	Not Applic
Horsehead Resource Development Co., Inc. (HRD) Monaca, PA (004) *Demonstration Date:* March 1991	Flame Reactor/Developer's Facility in Monaca, PA, using waste from National Smelting and Refining Company Superfund Site in Atlanta, GA	Regis Zagrocki 412-773-2289	Donald Oberacker 513-569-7510 Marta Richards 513-569-7783	Soil, Sludge, Industrial Solid Residues	Metals
Hrubetz Environmental Services, Inc. Dallas, TX (007) *Demonstration Date:* January - February 1993	HRUBOUT® Process/Kelly AFB in San Antonio, TX	Michael Hrubetz or Barbara Hrubetz 214-363-7833	Gordon Evans 513-569-7684	Soil	Not Applic

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TABLE B-2
COMPLETED *SITE* DEMONSTRATION PROGRAM PROJECTS AS OF OCTOBER 1993 (Continued)

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Inc
Hughes Environmental Systems, Inc. Manhattan Beach, CA (005) *Demonstration Date:* August 1991 - September 1993	Steam Enhanced Recovery Process/Fuel Spill Site in Huntington Beach, CA	Ron Van Sickle 310-616-6634	Paul dePercin 513-569-7797	Soil, Groundwater	Not Applic
Illinois Institute of Technology Research Institute/Halliburton NUS Oak Ridge, TN (007) *Demonstration Date:* August 1993	Radio Frequency Heating/Kelly AFB in San Antonio, TX	Paul Carpenter 904-283-6022 Clifton Blanchard 615-483-9900 Guggliam Sresty 312-567-4232	Laurel Staley 513-569-7863	Soil	Not Applic
International Waste Technologies/ Geo-Con, Inc. Wichita, KS and Monroeville, PA (001) (2 Demonstrations) *Demonstration Date:* April - May 1988	In Situ Solidification and Stabilization Process / General Electric Service Shop in Hialeah, FL	Jeff Newton 316-269-2660 Chris Ryan 412-856-7700	Mary Stinson 908-321-6683	Soil, Sediment	Nonspecif
Magnum Water Technology El Segundo, CA (007) *Demonstration Date:* March 1993	CAV-OX® Process/Edwards AFB, CA	Dale Cox 310-322-4143 Jack Simser 310-640-7000	Dick Eilers 513-569-7809	Groundwater, Wastewater	Not Applic
NOVATERRA, Inc. (formerly Toxic Treatments USA, Inc.) Torrance, CA (003) *Demonstration Date:* September 1989	In Situ Steam and Air Stripping/Annex Terminal, San Pedro, CA	Philip LaMori 310-843-3190	Paul dePercin 513-569-7797	Soil	Nonspecif Heavy Me
Peroxidation Systems, Inc. Tucson, AZ (006) *Demonstration Date:* September 1992	perox-pure? Advanced Oxidation Technology/Lawrence Livermore National Laboratory in Altamont Hills, CA	Chris Giggy 602-790-8383	Norma Lewis 513-569-7665	Groundwater, Wastewater	Not Applic
Resources Conservation Company Ellicott City, MD (001) *Demonstration Date:* July 1992	B.E.S.T. Solvent Extraction Technology/Grand Calumet River in Gary, IN	Lanny Weimer 301-596-6066	Mark Meckes 513-569-7348	Soil, Sludge, Sediment	Not Applic

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TABLE B-2
COMPLETED *SITE* DEMONSTRATION PROGRAM PROJECTS AS OF OCTOBER 1993 (Continued)

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Inc
Retech, Inc. Ukiah, CA (002) *Demonstration Date:* July 1991	Plasma Arc Vitrification/DOE Component Development and Integration Facility in Butte, MT	Ronald Womack or Leroy Leland 707-462-6522	Laurel Staley 513-569-7863	Soils, Sludge	Metals
Risk Reduction Engineering Laboratory Cincinnati, OH (006) *Demonstration Date:* August 1993	Base-Catalyzed Dechlorination Process/Koppers Company Superfund Site in Morrisville, NC	Charles Rogers 513-569-7626 Yei-Shong Shieh 215-832-0700	Terrence Lyons 513-569-7589	Soils, Sediments	Not Applic
Risk Reduction Engineering Laboratory Cincinnati, OH (007) *Demonstration Date:* November 1992	Volume Reduction Unit/ Escambia Wood Preserving Site in Pensacola, FL	Richard Griffiths 908-321-6629	Teri Richardson 513-569-7949	Soil	Metals
Risk Reduction Engineering Laboratory and IT Corporation Cincinnati, OH (004) *Demonstration Dates:* September 1988, December 1989, and August 1990	Debris Washing System/ Superfund Sites in Detroit, MI; Hopkinsville, KY; and Walker County, GA	Michael Taylor or Majid Dosani 513-782-4700	Naomi Barkley 513-569-7854	Debris	Nonspecif
Risk Reduction Engineering Laboratory and University of Cincinnati Cincinnati, OH (005) *Demonstration Date:* July 1991 - September 1992	Hydraulic Fracturing/Feasibility Studies Conducted in Oakbrook, IL, and Dayton, OH	Larry Murdoch 513-556-2526	Naomi Barkley 513-569-7854	Soil, Groundwater	Nonspecif
Risk Reduction Engineering Laboratory and USDA Forest Products Laboratory Cincinnati, OH (006) *Demonstration Date:* September 1991 - November 1992	Fungal Treatment Technology/ Brookhaven Wood Preserving in Brookhaven, MS	Richard Lamar 608-231-9469 John Glaser 513-569-7568	Kim Lisa Kreiton 513-569-7328	Soil	Not Applic

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TABLE B-2
COMPLETED *SITE* DEMONSTRATION PROGRAM PROJECTS AS OF OCTOBER 1993 (Continued)

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Inc
SBP Technologies, Inc. Stone Mountain, GA (005) *Demonstration Date:* October 1991	Membrane Filtration and Bioremediation/American Creosote Works in Pensacola, FL	David Drahos 404-498-6666	Kim Lisa Kreiton 513-569-7328	Groundwater, Soils, Sludges	Not Applic
Silicate Technology Corporation Scottsdale, AZ (003) *Demonstration Date:* November 1990	Chemical Fixation/Solidification Treatment Technologies/Selma Pressure Treating Site in Selma, CA	Stephen Pelger or Scott Larsen 602-948-7100	Edward Bates 513-569-7774	Soil, Sludge, Wastewater	Metals, Cy
J.R. Simplot Company[b] Pocatello, ID (007) *Demonstration Date:* July 1993	Biodegradation of Dinoseb/ Bowers Field in Ellensburg, WA	Dane Higdem 208-234-5367	Wendy Davis-Hoover 513-569-7206	Soil	Not Applic
J.R. Simplot Company[b] Pocatello, ID (007) *Demonstration Date:* September 1993 - October 1993	Biodegradation of Trinitrotoluene/DOD Site in St. Louis, MO	Dane Higdem 208-234-5367	Wendy Davis-Hoover 513-569-7206	Soil	Not Applic
SoilTech ATP Systems, Inc. Englewood, CO (005) (2 Demonstrations) *Demonstration Dates:* New York: May 1991 Illinois: June 1992	Anaerobic Thermal Processor/ Wide Beach Superfund Site in Brant, NY, and Waukegan Harbor Superfund Site in Waukegan, IL	Roger Nielson 303-290-8336 Joseph Hutton 219-926-8651	Paul dePercin 513-569-7797	Soil, Sludge, Refinery Wastes	Not Applic
Soliditech, Inc. Houston, TX (002) *Demonstration Date:* December 1988	Solidification and Stabilization/ Imperial Oil Company/ Champion Chemical Company Superfund Site in Morganville, NJ	Bill Stallworth 713-497-8558	Jack Hubbard 513-569-7507	Soil, Sludge	Metals, N Inorganics
Terra Vac, Inc. San Juan, PR (001) *Demonstration Date:* December 1987 - April 1988	In Situ Vacuum Extraction/ Groveland Wells Superfund Site in Groveland, MA	James Malot 809-723-9171	Mary Stinson 908-321-6683	Soil	Not Applic
Toronto Harbour Commission Toronto, Ontario, Canada (007) *Demonstration Date:* April - May 1992	Soil Recycling/Toronto Port Industrial District in Toronto, Ontario	Dennis Lang 416-863-2047	Teri Richardson 513-569-7949	Soil	Nonspecif

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TABLE B-2
COMPLETED *SITE* DEMONSTRATION PROGRAM PROJECTS AS OF OCTOBER 1993 (Continued)

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Inc
Ultrox International Santa Ana, CA (003) *Demonstration Date:* March 1989	Ultraviolet Radiation and Oxidation/Lorentz Barrel and Drum Company in San Jose, CA	David Fletcher 714-545-5557	Norma Lewis 513-569-7665	Groundwater, Leachate, Wastewater	Not Applic
EPA San Francisco, CA (007) *Demonstration Date:* June - July 1990	Excavation Techniques and Foam Suppression Methods/ McColl Superfund Site in Fullerton, CA	John Blevins 415-744-2241	Jack Hubbard 513-569-7507	Soil	Volatile In
WASTECH Inc. Oak Ridge, TN (004) *Demonstration Date:* August 1991	Solidification and Stabilization/ Robins AFB in Warner Robins, GA	Benjamin Peacock 615-483-6515	Terrence Lyons 513-569-7589	Soil, Sludge, Liquid Waste	Nonspecif Inorganics
Roy F. Weston, Inc. West Chester, PA (006) *Demonstration Date:* November - December 1991	Low Temperature Thermal Treatment (LT³®) System/ Anderson Development Company Superfund Site in Adrian, MI	Mike Cosmos 215-430-7423	Paul dePercin 513-569-7797	Soil, Sludge	Not Applic
Roy F. Weston, Inc./IEG Technologies Woodland Hills, CA (007) *Demonstration Date:* May - November 1993	UVB - Vacuum Vaporizing Well/March AFB, CA	Jeff Bannon or Ron Chu 818-596-6900 Eric Klingel 704-357-6090	Michelle Simon 513-569-7469	Groundwater	Not Applic

[b] From

Source: EPA, November 1993. *Superfund Innovative Technology Evaluation Program, Technology Profiles,* Sixth Editior

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FEDERAL DATA
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✍ INTRODUCTION

The profiles contained in this appendix were identified through a review of reports, articles, and publ Remediation Technologies Roundtable (FRTR) member agencies and telephone interviews with data b members include the U.S. Environmental Protection Agency (EPA), U.S. Department of Defense (DC Energy (DOE), and U.S. Department of the Interior (DOI). In addition, the National Aeronautics and (NASA) participates in FRTR meetings.

This appendix is a reference tool that provides information on those systems maintaining data on rem may be used by project managers as a pointer to repositories of technical information, or as a source useful to future system design. Each data base profile contains information on data elements, system software requirements, and access. The profiles also contain contacts for each system. A matrix sho characteristics of the data bases included in this document is provided in Table C-1. Table C-2 sum contained in the data base profiles.

Additional information sources are provided on pages C -50 through C-60. For each information sou address, telephone numbers, hours of operation, description of service, and the primary focus are pro

TABLE C-1
SYSTEM CHARACTERISTICS OF FEDERAL DATA BASES

System Name	Technology Description	Performance Data	Cost Data	Case Studies	Updated Periodically	User Fee	Pul Ac
Alternative Treatment Technology Information Center (ATTIC)	x	x	x	x	x		
Case Study Data System	x	x		x			
CLU-IN Bulletin Board System (BBS)	x			x	x		
Cost of Remedial Action Model (CORA)	x	x	x			x	
Defense Environmental Electronic Bulletin Board System (DEEBS)	x				x		
Defense Environmental Network Information Exchange (DENIX)	x				x		
Defense RDT&E Online System (DROLS)	x				x	x	
Energy Science and Technology Data Base	x	x	x		x	x	
Environmental Technical Information System (ETIS)	x				x	x	
Environmental Technologies Remedial Actions Data Exchange (EnviroTRADE)	x	x		x	x		
Environmental Technology Information System (TIS)	x	x	x		x		
Hazardous Waste Superfund Data Collection	x	x	x	x	x		

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TABLE C-1
SYSTEM CHARACTERISTICS OF FEDERAL DATA BASES
(CONTINUED)

System Name	Technology Description	Performance Data	Cost Data	Case Studies	Updated Periodically	User Fee	Pul Ac
Installation Restoration Data Management Information System (IRDMIS)					x		
National Technical Information Service Bibliographic Data Base	x	x	x	x	x	x	
New Technology from DOE (NTD)	x			x	x		
ProTech & the Technology Catalogue	x	x	x				
Record of Decision System (RODS)	x		x		x		
ReOpt: Electronic Encyclopedia of Remedial Action Options	x	x		x	x	x	
Research in Progress				x	x	x	
RREL Treatability Data Base	x	x			x		
Soil Transport and Fate Data Base					x		
Technology Integration System Support (TISS)	x	x	x	x	x		
Waste Management Information System (WMIS)	x			x	x		

TABLE C-2
SUMMARY TABLE OF FEDERAL DATA BASES

Name	Objective	Data/Technology Information	Hardware/Software
Alternative Treatment Technology Information Center (ATTIC)	ATTIC is an information retrieval network that provides site remediation managers with technical information on alternative treatment methods for remediating hazardous waste.	The data base contains abstracts from more than 2,000 technical references, including books, EPA publications, journal articles, and treatability studies.	A computer, modem, and communications software are required to access the system.
Case Study Data System	This data system stores and retrieves case-specific information to support rule and guidance development activities affecting facility siting, corrective action, and closure.	The data system contains more than 200 case studies that address topics such as floodplains, disposal technology, treatment, and environmental effects.	The data base system is written in dBase III and formatted for an IBM PC.
CLU-IN Bulletin Board System (BBS)	The system serves as a communications mechanism to assist hazardous waste cleanup professionals obtain current information about innovative cleanup technologies.	The system offers messages, bulletins, computer files, and data bases.	A computer, modem, and communications software are required to access the system.
Cost of Remedial Action Model (CORA)	This computerized expert model is designed to recommend remedial actions for Superfund hazardous	The model is comprised of two independent subsystems: an expert system that uses site	CORA is a stand-alone system requiring an IBM or compatible PC, MS-DOS environment, 640K RAM,

TABLE C-2
SUMMARY TABLE OF FEDERAL DATA BASES
(CONTINUED)

Name	Objective	Data/Technology Information	Hardware/Software
	waste sites and estimate the cost of these actions.	information to recommend a range of remedial response actions, and a cost system that develops cost estimates for the technologies selected.	and 5MB of hard disk space.
Defense Environmental Electronic Bulletin Board System (DEEBS)	This system serves as a centralized communications platform for disseminating DERP information pertaining to DOD's scheduled meetings, training, clean-up sites, and technologies.	The system provides user mail service, multi-user access, and upload/download features. It permits access to 800 number dial in and to other environmental data networks.	The system can be accessed with a dumb terminal or a PC with a modem and communications software.
Defense Environmental Network Information (DENIX)	To provide DOD personnel information on environmental, legislative, compliance, restoration, cleanup, and DOD guidance information.	DENIX provides the capability to review environmental publications online, send and receive electronic mail via DENIX host and the internet, and enter the interactive discussion forums on various subjects.	The system can be accessed only by DOD personnel. A password is necessary to access the system. DENIX is available online.
Defense RDT & E Online System (DROLS)	This bibliographic data base provides information on DOD's ongoing research and technology efforts.	The system provides access to three separate data bases: Research Work Unit Information System,	The system is available through dial-up to the Defense Technical Information Center's central

TABLE C-2
SUMMARY TABLE OF FEDERAL DATA BASES
(CONTINUED)

Name	Objective	Data/Technology Information	Hardware/Software
		Technical Report Data Base, and Independent Research and Development Data Base.	computer system.
Energy Science and Technology Data Base	This multidisciplinary bibliographic file contains worldwide references to basic and applied scientific and technical research literature.	The system includes references to journal literature, conferences, patents, book, monographs, theses, and engineering and software materials.	The system is available via dial-up through DOE's Integrated Technical Information System (ITIS) and to the public through DIALOG Information Services.
Environmental Technical Information System (ETIS)	This system is designed to help DOD conduct analyses to document environmental consequences of its activities.	ETIS's subsystems include data and information exchange on chemicals, regulations, hazardous materials, and hazardous wastes.	The system is available via dial-up with a computer, modem, and communications software capable of VT-100 emulation.
Environmental Technologies Remedial Actions Data Exchange (EnviroTRADE)	This system is being designed to help facilitate the exchange of environmental restoration and waste management technologies.	The system will contain information on international environmental restoration and waste management technologies, organizations, sites, activities, funding, and contacts.	The system will be available to DOE users in 1993 and other users at a later date. Hardware and software requirements have not been finalized.
Environmental Technology Information System (TIS)	This system provides technical experts with	The system offers advice on screening remedial options	The system can be accessed via dial-up using a PC,

TABLE C-2
SUMMARY TABLE OF FEDERAL DATA BASES
(CONTINUED)

Name	Objective	Data/Technology Information	Hardware/Software
	information aboutpotential waste cleanup technologies.	based on site-specific input information.	minicomputer, or mainframe. Special software is required.
Hazardous Waste Superfund Collection Data Base	This online bibliographic data base correspondsto a special collection of hazardous waste documents located throughout the EPA library network.	The system includes bibliographic references and abstracts on EPA reports, OSWER policy and guidance directives, legislation, regulations, and non-government books.	The system is available online through the EPA Online Library System or it can be downloaded from CLU-IN. Both methods of access require a PC, modem, and communica-tions software.
Installation Restoration Data Management Information System (IRDMIS)	This data base supports technical and managerial requirements of the Army's Installation Restoration Program and other environmental efforts.	The data base contains analytical results from chemical, geotechnical, and radiological sampling.	The system requires software provided by USAEC.
National Technical Information Service (NTIS) Bibliographic Data Base	This is a bibliographic retrieval system that references the reports of major federal agencies.	The system consists of unclassified government-sponsored research, development, and engineering reports, as well as other analyses prepared by government agencies and their contractors.	The data base is available through a number of commercial data base vendors, such as DIALOG, BRS, STN, Orbit, and CISTI.
New Technology from DOE (NTD)	This system is designed to disseminate information	The system includes technology descriptions,	The data base is available to DOE users with a computer,

TABLE C-2
SUMMARY TABLE OF FEDERAL DATA BASES
(CONTINUED)

Name	Objective	Data/Technology Information	Hardware/Software
	about DOE research results that have potential for commercialization.	patent status, secondary applications, literature citations, and DOE information.	modem, and communications software capable of VT-100 emulation.
Protech and the Technology Catalogue	1. Minimize the time and effort that field personnel spend providing information on their technologies. 2. Provide more detailed technical cost performance data on deployable technologies advanced by DOE's Office of Technology Development (EM-50) to its customers, DOE's Offices of Waste Management (EM-30) and Environmental Restoration (EM-40) and their contractors.	Description of technologies supported under Integrated Demonstrations (IDs).	Macintosh Computer Platform.
Records of Decision System (RODS)	This system provides comprehensive information on Superfund Records of Decision for hazardous Waste cleanup sites nationwide.	The data base contains the full text of all signed Records of Decision.	A personal computer, modem and communications software are required to access the system.
ReOpt: Electronic	The system provides	The system contains	The system runs on IBM-PC

TABLE C-2
SUMMARY TABLE OF FEDERAL DATA BASES
(CONTINUED)

Name	Objective	Data/Technology Information	Hardware/Software
Encyclopedia ofRemedial Action Options	information collected from EPA, DOE, and other sources about remedial action technologies.	diagrams, descriptions, engineering or design parameters, contaminants treated, technical and regulatory constraints, and other information for about 90 technologies.	and compatibles in a WINDOWS? environment and Macintosh II (or greater). It requires at least 5 megabytes of RAM and 12 megabytes of hard disk space. OMNIS SEVEN? software is embedded in the system, and a fee is required for a license and installation materials.
Research in Progress Data Base	This data base bridges the information gap that occurs between initiation and completion of a research project by providing information about ongoing research projects.	The data base contains administrative and technical information about all unclassified current and recently completed research projects performed or funded by DOE.	A computer, modem, and communications software capable of VT-100 emulation are required to access the system.
RREL Treatability Data Base	The data base provides treatability data for the removal/destruction of organic and inorganic chemicals in aqueous and solid media.	The system contains 1,207 compounds with 13,500 data sets.	The data base is menu-driven and can be loaded on an IBM or compatible PC with DOS Version 2.0 to 6.0, 640K RAM, and 7MB of hard disk storage. It is also available for downloading through CLU-IN.
Soil Transport and Fate Data	The data base provides	The data base includes	The data base will run on

TABLE C-2
SUMMARY TABLE OF FEDERAL DATA BASES
(CONTINUED)

Name	Objective	Data/Technology Information	Hardware/Software
Base and Model Management System	information on chemical properties, toxicity, transformation, and bioaccumulation for hundreds of chemical compounds.	information on approximately 400 chemicals as well as models for predicting the fate and transport of hazardous organic constituents in the vadose zone.	any IBM-compatible computer with 640K RAM, 12.5 MB of hard disk storage, and a math coprocessor.
Technology Integration System Support (TISS)	This system supports DOE in the development of new environmental technologies by providing a central focus for information exchange between DOE and industry, other federal agencies (OFAs), and universities.	Includes DOE environmental technologies, points of contact, DOE documents, vendor information, DOE procurement activities, and requestor data bases.	NextStep system, which runs object-oriented Knowledge Base on 486 platform.
Waste Management Information System (WMIS)	The system provides an accurate and complete resource for the explanation and selection of appropriate technologies for handling hazardous, mixed, radioactive, or remedial action waste.	The system includes waste generation/process data, information on T/S/D capabilities, and waste profiles.	WMIS resides on a Novel local area network at DOE.

✍ C.1 ALTERNATIVE TREATMENT TECHNOLOGY INFORMATION CENTER (ATTIC)

Sponsoring Agency: U.S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
Edison, NJ

Description of Services: ATTIC is a comprehensive information retrieval system containing data on alternative treatment technologies for hazardous waste. It contains several data bases that are accessed through a free public access bulletin board. The central component of ATTIC is the Treatment Technology Data base, which contains abstracts andsummaries from technical documents that are free-text searchable. Search results can then be downloaded for review on the user's computer. Access is also provided to a number of other data bases, including a technology performance/treatability study data base and an underground storage tank data base. New features include full text downloadable files of key treatment technology documents, including Superfund Innovative Technology Evaluation (SITE) program documents. The bulletin board also features news items, bulletins, and E-mail.

Data: ATTIC users can access four data bases directly through the BBS:

- ATTIC Data Base (contains more than 2,000 records on alternative treatment technologies for remediating hazardous waste).
- RREL Treatability DataBase (provides data on the treatability of contaminated water and soil).
- Technical Assistance Directory (identifies experts on a given technology or contaminant).
- Calendar of Events (lists of upcoming conferences and events).

Access: Users can dial directly into the ATTIC system through their own computer by dialing (703) 908-2138. Users without access to a computer or those with questions about the system can contact the system operator for assistance.

Hardware/Software: ATTIC is accessible byany PC or terminal equipped with

communications software and a modem.

Contact:

ATTIC Project Manager
EPA/RREL
2890 Woodbridge Ave. (MS-106)
Edison, NJ 08837
(908) 321-6677
FAX (908) 906-6990

✍ C.2 CASE STUDY DATA SYSTEM

Sponsoring Agency:

U.S. Environmental Protection Agency
Office of Solid Waste
Washington, DC

Description of Services:

The Case Study Data System (CSDS) is an inventory of more than 220 case studies that were developed to support RCRA rule and guidance development activities affecting facility location, RCRA Corrective Action, and closure. The system was completed in April 1990. The system can be used to identify case studies that contain information on treatment technologies used at various specific hazardous waste sites.

Data:

The case studies are organized by number in a library at EPA. The CSDS is the indexing system for this library that identifies appropriate case studies by using data fields and keywords. The case studies contain formatted information about the geology, general problems, processes associated with waste handling, and treatment technologies (including innovative, standard, and regular procedures) for specific sites. The case studies address a variety of topics such as floodplains, disposal technology, treatment, and environmental effects.

Access:

The data base is available for downloading from the Cleanup Information (CLU-IN) Bulletin Board. The manual is available to those who fill out an online script questionnaire on CLU-IN requesting a copy.

Hardware/Software:

The Case Study Data System is written in dBase III and is formatted for use on an IBM PC or compatible computer.

Contact:

Andy O'Palko
EPA/Office of Solid Waste
Mail Code 5303W
401 M St., SW
Washington, DC 20460
(703) 308-8646
FAX (703) 308-8617

✍ C.3 CLEANUP INFORMATION BULLETIN BOARD SYSTEM (CLU-IN)

Sponsoring Agency: U.S. Environmental Protection Agency
Technology Innovation Office
Washington, DC

Description of Services: The RCRA CLU-IN is designed for hazardous waste cleanup professionals to use in finding current events information about innovative technologies, consulting with one another online, and accessing data bases. CLU-IN is used by those involved in the cleanup of Superfund, RCRA corrective action, and underground storage tank sites, including EPA staff, other federal and state personnel, consulting engineers, technology vendors, remediation contractors, researchers, community groups, and the public.

Data: CLU-IN has the following features:

- Electronic messages allowing users to leave messages for individual users or to a large audience of users.
- Bulletins that can be read online, such as summaries of *Federal Register* and *Commerce Business Daily* notices on hazardous waste, descriptions and listings of EPA documents, a calendar of EPA training courses, notices of upcoming meetings and SITE Program demonstrations, and the text of EPA newsletters.
- Files that can be downloaded for use on the user's computer—such as directories, data bases, models, and EPA documents.
- Online Data Bases that can be searched on CLU-IN.

In addition, CLU-IN has special interest group areas (SIGs) with all of the functions of the main board, but limited to a particular group or subject area. Examples of SIGs include treatability study investigation, OSC/ removal, and groundwater technologies.

Access: Users can dial directly into CLU-IN at (301) 589-8366.

Communications settings are:

- 8 data bits
- 1 stop bit
- No parity
- 1200-9600 baud
- VT-100 terminal emulation

Hardware/Software: To access CLU-IN, you will need a computer, modem, telephone line, and communications software.

Contact: CLU-IN System Operator
(301) 589-8368
FAX (301) 589-8487

✍ C.4 COST OF REMEDIAL ACTION (CORA) MODEL

Sponsoring Agency:

U.S. Environmental Protection Agency
Office of Emergency and Remedial Response
Washington, DC

Description of Services:

The Cost of Remedial Action (CORA) Model is a computerized expert advisor used to recommend remedial actions for Superfund hazardous waste sites and estimate their costs. The stand-alone PC-based system may also be used for RCRA corrective action sites. The model is designed for both current site-specific estimates and for program budgeting and planning. The system provides recommendations for remedial action technologies on a site-specific basis, and provides a method to estimate remedial action costs in the pre-feasibility stage of analysis.

Data:

The CORA Model is comprised of two independent subsystems:

- Expert System—allows a user to enter site information generally accessible at the remedial investigation stage and recommends a range of remedial response actions from among 44 technology descriptions contained in the system. It includes descriptions of innovative treatment technologies:

  - Soil vapor extraction
  - Solidification
  - Soil slurry bioreactor
  - Pressure filtration
  - Soil flushing
  - In situ biodegradation
  - In situ stabilization

- Cost System—develops order of magnitude (+50/-30%) cost estimates for the technologies selected and may be used to independently assess remedy recommendations from other sources.

Access:

The model is available from the contact below for a cost of $280, which includes a run-time version of the system and 1 hour of technical assistance.

Hardware/Software:

The CORA Model is a stand-alone application, not designed for LAN use. The following are the hardware specifications:

- IBM-compatible PC
- MS-DOS environment
- 640 kilobytes of RAM
- 5 megabytes of hard disk space

Contact:

CORA Hotline:
Jaya Zyman
CH2M Hill
625 Herndon Parkway
Herndon, VA 22070
(703) 478-3566
FAX (703) 4810980

✍ C.5 DEFENSE ENVIRONMENTAL ELECTRONIC BULLETIN BOARD SYSTEM (DEEBBS)

Sponsoring Agency: U.S. Department of Defense
Washington, DC

Description of Services: The Defense Environmental Electronic Bulletin Board System (DEEBBS) serves as a centralized communication platform for disseminating Defense Environmental Restoration Program (DERP) information pertaining to DOD's cleanup sites, technologies, program policy and guidance, scheduled meetings, and training. It fosters online communications and technology transfer among DOD components.

Data: DEEBBS contains a messaging component as well as the capability for file transfers. DEEBBS includes information on cleanup technologies, policies, and regulatory information.

Access: DEEBBS is an online system available only to DOD personnel.

Hardware/Software: The system can be accessed with a dumb terminal or a computer, modem, and communications software.

Contact: For online access:
Kim Grein
CERL/USACE
P.O. Box 9005
Champaign, IL 61826-9005
(800) USA-CERL, ext. 652
FAX (217) 373-7222

Patricia Jensen
Office of the Deputy Assistant Secretary of Defense (Environment)
Pentagon, Room 3D833
Washington, DC 20301-8000
(703) 695-7820
FAX (703) 697-7548

✍ C.6 DEFENSE ENVIRONMENTAL NETWORK INFORMATION EXCHANGE (DENIX)

Sponsoring Agency: U.S. Department of Defense

Description of Services: Defense Environmental Network Information Exchange (DENIX) was developed to provide DOD personnel in the environmental arena with a central communications platform that allows timely access to environmental, legislative, compliance restoration, cleanup, and DOD guidance information.

Data: The following information is available on the DENIX data base.

- Current world, national, federal, and state news.
- Service-specific news, events, and reports.
- Current policy, guidance, and directives.
- Legislative and regulatory news.
- Environmental publications.
- Training directories.
- Environmental contacts directory.
- Presidential and Congressional calendars.
- Discussion forums.

Access: The data base is available only to DOD personnel. Application procedures and a password are required to access the data base.

Hardware/Software: DENIX provides the capability to review environmental publications online, send and receive electronic mail via the DENIX host and the Internet, enter into interactive discussion forums about various subject areas, upload and download data files, and access listings of environmental training.

Contact:
Kim Grein
U.S. Army Corps of Engineers
P.O. Box 9005
Champaign, IL 61826-9005
(217) 373-4519
FAX (217) 373-4421

✍ C.7 DEFENSE RDT&E Online System (DROLS)

Sponsoring Agency:

U.S. Department of Defense
Defense Technical Information Center

Description of Services:

The Defense RDT&E Online System (DROLS) was developed by the Defense Technical Information Center (DTIC) to provide online access to its data collection of ongoing DOD research and technology efforts. The system includes citations to reports distributed by DOD. DROLS is used to identify, input, and order documents. The system can be searched by author, source, date, title, subject, project, contract, report numbers, and funding sources.

Data:

DROLS provides access to three separate data bases:

- Research and Technology Work Unit Information System (WUIS) Data Base (containing ongoing DOD research and technology efforts at the work unit level).
- Technical Report Data Base (consisting of bibliographic records of technical reports submitted to DTIC).
- Independent Research and Development (IR&D) Data Base (containing contractors' independent research and development efforts shared with DOD). This data base is proprietary and accessible only to classified DOD terminals.

Access:

DROLS is an online system that can beaccessed through the DTIC central computer system. To subscribe to the online system, contact DTIC at the number below.

Hardware/Software:

Classified users are required to use dedicated phone lines requiring special encryption equipment or STU-III installation. Dial-up or dedicated access to DROLS is available for unclassified users.

Contact:

Defense Technical Information Center
Attn: Registration and Services Branch (DTIGBCS)
Building 5, Cameron Station
Alexandria, VA 22304
(703) 274-6871

✍ C.8 ENERGY SCIENCE AND TECHNOLOGY DATA BASE

Sponsoring Agency:

U.S. Department of Energy
Office of Science and Technical Information
Oak Ridge, TN

Description of Services:

The Energy Science and Technology Data Base is a multi-disciplinary bibliographic data base containing references to basic and applied scientific and technical energy- and nuclear-science related research literature worldwide. The information is collected for use by government managers and researchers at the DOE National Laboratories, other DOE researchers, and the public. Abstracts are included for most records. Items date from 1976 to the present, with older literature included in some subject areas.

Data:

The Energy Science and Technology Data Base includes references to journal literature, conferences, patents, books, monographs, theses, and engineering and software materials. Approximately 50% of the references are from foreign sources. Coverage includes the following areas of energy-related research:

- Engineering
- Environmental sciences
- Geosciences
- Hazardous waste management
- Materials handling

The data base is continually updated by about 180,000 records per year. The system can be searched by author, title, subject, and research organization.

Access:

The Energy Science and Technology Data Base is available to the public through DIALOG Information Services (a commercial system) for a fee. A limited version of the system is also available to DOE employees, DOE contractors, and other government agencies through DOE's Integrated Technical Information System (ITIS). In addition, DIALOG has a companion file called Nuclear Science Abstracts, covering the period from 1947 to mid-1976, that is not available through ITIS.

Hardware/Software:

Users can dial into the system through DIALOG with a computer, modem, and communications software. DOE users should contact ITIS for access.

Contact:

Integrated Technical Information System (ITIS)
DOE/OSTI
P.O. Box 62
Oak Ridge, TN 37831
(615) 576-1222

DIALOG Information Services
(800) 334-2564

✍ C.9 ENVIRONMENTAL TECHNICAL INFORMATION SYSTEM (ETIS)

Sponsoring Agency: U.S. Army Corps of Engineers
Construction Engineering Research Laboratory
Champaign, IL

Description of Services: The Environmental Technical Information System (ETIS) is a minicomputer-based system designed to help DOD personnel conduct environmental analyses to document environmental consequences of its activities. The system is now used by other federal agencies as well as the general public.

Data: The ETIS system contains a number of subsystems including:

- Environmental Impact Computer System (to identify potential environmental impacts of programs or activities).
- Computer-Aided Environmental Legislative Data System (CELDS) (to allow users to search Federal and State environmental regulations by keywords).
- Hazardous Materials Management System (contains data on hazardous chemicals including physical and chemical properties, guidance for handling, storage, and transportation).
- Soils Information Retrieval System (provides information on soils anywhere in the United States).
- Hazardous Waste Management Information System (assists in record-keeping for and management of hazardous waste at military bases).
- Electronic bulletin boards (for networking with others involved in site cleanup). Electronic bulletin boards on ETIS include:
    - Discuss with Experts Environmental Problems (DEEP)—used primarily by installation environmental officers. Covers air quality, asbestos, wildlife conservation, cultural resources,

compliance, environmental management, noise conflict, resource conservation and recovery, solid waste, and water quality. Lists environmental experts at each Army and Air Force base as well as training courses and job listings.

- Hazardous Expertise (HAZE)—for users involved in hazardous materials handling and disposal. Covers disposal methods, labeling, good management practices, hazardous waste minimization, testing and dispensing, spill control, hazardous materials storage, and hazardous waste treatment.

Access: Users can dial into ETIS once they have set up an account. To obtain an account, military, DOE, and EPA users should contact the CERL contact below. Private sector and other users should contact the ETIS Support Center. There is a connect hour fee for non-military and non-EPA users.

Hardware/Software: ETIS is accessible by a computer or terminal equipped with communications software and a modem. VT-100 emulation is recommended.

Contact:

ETIS Support Center
Elizabeth Dennison
1003 West Nevada St.
Urbana, IL 61801
(217) 333-1369

Kim Grein
CERL/USACE
PO Box 9005
Champaign, IL 61826-9005
(800) USA-CERL, ext. 652
FAX (217) 373-7222

✍ C.10 ENVIRONMENTAL TECHNOLOGIES REMEDIAL ACTIONS DATA EXCHANGE (EnviroTRADE)

Sponsoring Agency: U.S. Department of Energy
Office of Environmental Restoration and Waste Management

Washington, DC

Description of Services: The Environmental Technologies Remedial Actions Data Exchange (EnviroTRADE) is an international information system that will facilitate the exchange of environmental restoration and waste management technologies.

Data: EnviroTRADE contains both foreign and domestic technologies and needs profiles. Users can identify possible matches between worldwide environmental restoration and waste management needs and technologies. EnviroTRADE will also provide general information on international environmental restoration and waste management organizations, sites, activities, funding, and contracts. The system is user friendly, providing visually oriented information such as photographs, graphics, maps, and diagrams of technologies and sites. The system has expanded into a fully functionally geographical information system (GIS).

Hardware/Software: EnviroTRADE is in the final stages of development. DOE plans to make it available to DOE users in 1993 with domestic and international networking to follow. Informix/Online is the Relational Data Base Management System and the Graphical user Interface is DevGuide. EnviroTRADE is presently being developed on a SUN workstation and will migrated to the PC and Macintosh in FY93.

Access: Network access as planned will be online through Internet.

Contact: Susan Johnson
International Technology Exchange Program
DOE
Trevion II, EM-523
Washington, DC 20585-0002
(301) 903-7930

✍ C.11 ENVIRONMENTAL TECHNOLOGY INFORMATION SYSTEM (TIS)

Sponsoring Agency:

Department of Energy
Idaho National Engineering Laboratory
Idaho Falls, ID

Description of Services:

The Environmental Technology Information System (TIS) contains technology information relative to innovative and available technologies to support environmental management. Cost, vendor information, previous uses (if any), and measures of effectiveness are included when those data are available in the literature.

Uses of the TIS include:

- Online access to information regarding technologies for environmental management processes.
- Aid in identification of currently listed technologies.
- Aid in access of other computerized information (through "launch" of other computer programs).
- Documentation of technology choices.
- Linkage of information from one document to another.
- Data collection and storage.
- Full-text retrieval of technology information.

Data:

The TIS provides descriptive information gathered from journals and other references, conference proceedings, and expert experience. Retrieval of information is by any word found within the TIS. Expert knowledge is built into the TIS by use of logic trees to aid the uninitiated user. Current users continue to add information to the TIS.

Access:

While the TIS development project is not currently funded, access of the present system is available to the DOE and its contractors upon request. It is possible that the TIS will be "privatized."

Hardware/Software: TIS resides on a VAX/DEC 5800 ethernet server, which is accessible by IBM-compatible or Macintosh PC, minicomputer, or mainframe. A "client piece" of the "Topic" software is required.

Contact:

Claire Ross
DOE/Idaho National Engineering Laboratory
P.O. Box 1625-3970
Idaho Falls, ID 83415
(208) 526-0614
FAX (208) 526-6802

✍ C.12 HAZARDOUS WASTE SUPERFUND COLLECTION DATA BASE

Sponsoring Agency: U.S. Environmental Protection Agency
Washington, DC

Description of Services: The Hazardous Waste Superfund Collection is a special collection within the EPA Headquarters Library on the subject of hazardous waste. The Hazardous Waste Superfund Collection Data Base (HWSFD) is a data base containing bibliographic references and abstracts for the documents in the collection. The data base is designed to better meet the information needs of EPA staff by making key documents and services more readily available through the EPA library network. The system provides:

- A unified resource of major hazardous waste reports, books and journals available through the EPA library network.
- Current information to assist EPA staff in making timely and effective policy and regulatory decisions.
- Assistance in the transfer of hazardous waste information from the EPA to the states as part of the Agency's technology transfer effort.

Data: Continually growing, the HWSFD contains abstracts of books, legislation, regulations, reports from federal agencies, EPA Office of Solid Waste and Emergency Response (OSWER) policy and guidance directives, and EPA reports from selected program offices.

Entries can be searched by the following categories:

- Keywords (from a thesaurus)
- Title
- EPA program office
- Date
- Author
- Abstract

The HWSFD is updated quarterly. Selected documents from the collection are distributed to the 10 EPA regional libraries as well as to EPA laboratory libraries in Ada, OK;

Cincinnati, OH; Edison, NJ; Las Vegas, NV; Research Triangle Park, NC; and the National Enforcement Investigations Center in Denver, CO.

Access:

The Data Base is available to the public through two sources: the EPA Online Library System (OLS), which resides on the EPA mainframe (online version), and files that can be downloaded from EPA's CLU-IN Bulletin Board (PC version). To access either version, a user will need a computer, modem, and communications software. The number to dial into the online version is (919) 549 - 0720. The communications parameters are as follows:

- 300-9600 baud
- 7 data bits
- 1 stop bit
- Even parity

At the first prompt, type **IBMPSI**.
At the second prompt, choose the option for **OLS**.
To log off, type **QUIT** and follow the prompts.

For user support, call (800) 334-2405. For an OLS user manual, call (919) 541-2777.

Files to assemble the PC version can be downloaded from the CLU-IN Bulletin Board by dialing 301-589-8366. Parameters are:

- 8 data bits
- 1 stop bit
- No parity
- 1200-9600 Baud

Hardware/Software:

Both versions can be accessed with a PC, modem, and communications software.

Contact:

Felice Sacks
Hazardous Waste Superfund Collection
EPA Headquarters Library
Mail Code: PM-211A
401 M St., SW
Washington, DC 20460
(202) 260-3021

CLU-IN Help Line

(301) 589-8368

✍ C.13 INSTALLATION RESTORATION DATA MANAGEMENT INFORMATION SYSTEM

Sponsoring Agency: U.S. Army Environmental Center (USAEC)
Aberdeen Proving Ground, MD

Description of Services: The Installation Restoration Data Management Information System (IRDMIS) exists to support the technical and managerial requirements of the Army's Installation Restoration Program (IRP) and other environmental efforts of the USAEC (formerly the U.S. Toxic and Hazardous Materials Agency). Since 1975, more than 5 million technical data records have been collected and stored in the IRDMIS. These records represent information collected from over 100 Army installations.

Data: The records contain information on:

- Geodetic map coordinates of all sampling efforts.
- Digitized map information pertaining to installation boundaries and other key features.
- Geodetic elevations.
- Field drilling procedures and sampling.
- Water table measurements.
- Chemical sampling and analytical results.
- Radiological sampling and results.
- Meteorological information.
- Standards for specific analytes.
- Method descriptions of chemical, geotechnical, and radiological sampling and analysis procedures.

Data consist primarily of analytical results from chemical, geotechnical, and radiological sampling, coupled with sampling location information. A printed Data Dictionary specifying data base filed definitions, acceptable entries, and file formats is available upon request.

The IRDMIS data are stored in a relational data base with menus for accessing data and producing reports. Graphical display capabilities are provided so that users can interactively view and manipulate data in two and three dimensions.

Access: The system is available to USAEC project managers and contractors actively submitting data into IRDMIS. Contractors are restricted to data concerning their respective activities only. Access by other federal and state agencies are handled on a case by case basis.

Hardware/Software: Users are provided with DOS-based software to access the data base.

Contact:

Jim Wood
USAEC
Attn: CETHA-Room I
Building E, 4462T
Aberdeen Proving Ground, MD 21010-5401
(410) 671-1655

✍ C.14 NATIONAL TECHNICAL INFORMATION SERVICES (NTIS) BIBLIOGRAPHIC DATA BASE

Sponsoring Agency: U.S. Department of Commerce
Springfield, VA

Description of Services: The National Technical Information Service (NTIS) Bibliographic Data Base is a self-supporting agency of the U.S. Department of Commerce and is the largest single source for public access to federally produced information. NTIS is the federal agencycharged with collecting and distributing federal scientific, technical, and engineering information. The NTIS collection covers current technologies, business and management studies, foreign and domestic trade, environment and energy, health, social sciences, general statistics, and hundreds of other areas. When government agencies and their contractors forward reports and other items to NTIS, these items are entered into the NTIS computerized bibliographic data base and become part of the NTIS archive.

Data: The NTIS bibliographic data base contains data about federally generated machine-readable data files and software, U.S. government inventions available for licensing, reports on new technologies developed by federal agencies, federally generated translations, and reports prepared by non-U.S. government agencies. An increasing proportion of the data base consists of unpublished material originating outside the United States. Most NTIS records include an abstract.

Access: The NTIS data base is available to the public through a number of commercial vendors including:

- BRS (800-345-4277)
- CISTI (613-993-1210/in Canada)
- DIALOG (800-334-2564)
- ORBIT (800-456-7248, 703-442-0900/in Virginia)
- STN International (800-848-6533)

Some of these systems also allow ordering printed copies of documents from the NTIS collection. NTIS also allows ordering of documents from the sales desk (703-487-4650).

The data base is also available on CD-ROMs from a number of vendors.

Hardware/Software: The hardware and software required to access NTIS online depend upon the individual system used, but generally include a computer, modem, and communications software for dial-in access and a computer and CD-ROM drive for a CD-ROM version.

Contact: National Technical Information Service
U.S. Department of Commerce
Springfield, VA 22161
(703) 487-4650
FAX (703) 321-8547

✍ C.15 NEW TECHNOLOGY FROM DOE (NTD)

Sponsoring Agency:

U.S. Department of Energy
Office of Science and Technical Information
Oak Ridge, TN

Description of Services:

New Technology from DOE (NTD) contains brief descriptions of DOE research results that have potential for commercialization by U.S. industries. This data base is the centralized source of online informatio n on DOE technical innovations and advancements.

Data:

Each NTD record includes a technology description, patent status, secondary or spinoff applications, literature citations, DOE laboratory and sponsoring information, subject descriptors, and a contact for further information. The NTD currently contains 1,200 records from 1986 to the present. It is anticipated that older records dating from 1983 will be added to the data base.

Access:

The data base is available to DOE and its contractors through the Integrated Technical Information System (ITIS). Public access is provided through the National Technical Information Service's Technology Transfer Program.

Hardware/Software:

DOE and its contractors can access the ITIS using a computer, modem, and commun ications software capable of VT-100 emulation.

Contact:

Integrated Technical Information System
DOE/Office of Science and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(615) 576-1222

Technology Transfer Program
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4738

✍ C.16 PROSPECTIVE TECHNOLOGY (PROTECH) AND THE TECHNOLOGY CATALOGUE

Sponsoring Agency: U.S. Department of Energy
Office of Environmental Restoration and Waste Management
Washington, DC

Description of Services: Computer-based communication tool to describe innovative environmental cleanup technologies. ProTech can provide management support to IDCs and DOE Office of Technology Development personnel as well as minimize the time and effort that field personnel spend providing information on their technologies. It will provide more detailed technical cost performance data on deployable technologies advanced by the Office of Technology Development to its customers, DOE's Offices of Waste Management (EM-30) and Environmental Restoration (EM-40) and their contractors. The Technology Catalogue will take and use the data produced by Protech and be distributed to personnel throughout DOE and its laboratory system.

Data: ProTech is a prototype system that has been approved to become a national system to describe innovative environmental cleanup technologies. The user is presented with a schematic that divides all technologies into five categories: drilling, characterization and monitoring, extraction, above-ground treatment, and in-ground destruction and/or immobilization of contaminants. Each of these categories are divided into "ID technologies" and "baseline technologies." The user can click on any technology and pull up a fact sheet describing the need and objective of the technology and a graphic describing the components of the technology.

Hardware/Software: Macintosh computer platform.

Access: Still in prototype. System is expected to be ready late May or June of 1993.

Contact:

ProTech:

David Biancosino (DOE)
(301) 903-7961

Gretchen McCabe (Battelle Seattle Research Center)
(206) 528-3338

Technology Catalogue:

Joe Paladino (DOE-HQ)
(301) 903-7449

Nancy Prindle (Sandia National Labs)
(505) 844-7227

✍ C.17 RECORDS OF DECISION SYSTEM (RODS)

Sponsoring Agency:

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Washington, DC

Description of Services:

The Records of Decision System (RODS) is an online data base containing the full-text of the Superfund Records of Decision for National Priorities List sites nationwide. The Record of Decision contains information about the remediation technology to be used for a site, including the justification for why the technology was chosen. The RODS system can be used to:

- Search for a Record of Decision for a particular Superfund site
- Search for Records of Decision for sites with similar conditions, wastes, or media
- Search for Records of Decision for sites that use a particular technology

Data:

Each record in the RODS system contains the text of a single Record of Decision (ROD). A Record of Decision describes EPA's selection of the cleanup method to be used at a site. The ROD usually includes a history of the site, description of alternatives for cleaning up the site, rationale for the chosen cleanup method, cost estimates, and a responsiveness summary of the public comments received. The system can be searched by region, state, site name, ROD date, ROD ID number, media, contaminant, selected keywords, remedy, abstract, and full text.

Access:

Direct access to RODS is available only to EPA staff members and firms that have relevant EPA contracts. Contact the RODS Help Line for an account. For those who are not eligible for direct access, searches will be done by an information specialist at the RODS Help Line.

Hardware/Software:

RODS is located on EPA's mainframe computer in Research Triangle Park, NC, and is accessible through a computer, modem, and communications software. EPA employees may have direct access to the RODS system through their LANs or through access to the EPA data

switch.

Contact:

Jalania Ellis
EPA/OERR
401 M Street, SW
Mail Code 5201G
Washington, DC 20460
(703) 603-8889

✍ C.18 REOPT: ELECTRONIC ENCYCLOPEDIA OF REMEDIAL ACTION OPTIONS

Sponsoring Agency: Battelle Pacific Northwest Laboratories
Richland, WA

Description of Services: ReOpt is a user-friendly personal computer program that provides information about remedial action technologies. The information contained in ReOpt is derived from a number of sources, including DOE, EPA, and industry sources. ReOpt provides descriptions of approximately 90 technologies, breaking the information into useable categories of information, including application and regulatory information for nearly 850 contaminants. ReOpt was developed for DOE as part of the Remedial Action Assessment System (RAAS) project.

Data: For each technology, ReOpt contains information for the following categories:

- Flow diagram
- Description
- Engineering or design parameters.
- Contaminant applicability.
- Data Requirements.
- Associated technologies.
- Technical constraints for site, medium, and contaminant.
- Regulatory Constraints for site, medium, and contaminant.
- References.
- Previous/Applications.

ReOpt allows users to search by media, contaminant, and the way the functional manner in which the user wants to restore the site (such as, in situ treatment) to focus the analysis of those technologies potentially applicable to the

scenario.

Access:

The system is available on diskette for federal government users and their contractors under a Limited Government License from the Energy Science and Technology Software Center (ESTSC). ReOpt is available for purchase for non-federal and commercial use through Sierra Geophysics (Halliburton Industries) located in Kirkland, WA, 1-800-826-7644, ext. 120.

Hardware/Software:

ReOpt is available to run on IBM-PC and compatibles in a WINDOWS? environment and Macintosh II (or greater) computer systems. The system requires a high-resolution color monitor (supporting 640 x 480 pixels); a mouse; a 3.5" high density disk drive; at least 5MB of RAM; and approximately 12MB hard disk storage space. The system contains an embedded data base software product, OMBIS SEVEN? by Blyth Corporation and requires that a licensing fee be paid to obtain this license and the installation materials.

Contact:

Energy Science and Technology Software Center
(615) 576-2606

Janet Bryant
Battelle - Pacific Northwest Laboratory
P.O. Box 999, MSIN: K7-94
Richland, WA 99352

RAAS/ReOpt FAX Hotline: (509) 375-6417

✍ C.19 RESEARCH IN PROGRESS (RIP) DATA BASE

Sponsoring Agency:

U.S. Department of Energy
Office of Scientific and Technical Information
Oak Ridge, TN

Description of Services:

The Research in Progress (RIP) Data Base contains administrative and technical information about all unclassified current and recently completed research projects performed funded by DOE. This file bridges the information gap that occurs between initiation and completion of a research project. It serves as a technology transfer medium, a management information system for use in program planning and implementation, a system for current awareness and networking for the scientific community, and a resource base for publishing summaries of research in specific programmatic areas.

Data:

RIP contains information on approximately 23,000 DOE research efforts. Records are maintained for five years after project completion. All information on file is updated annually or when significant changes occur. With each annual data base update, researchers may change the information to reflect current work.

Access:

RIP is available to DOE and its contractors through the DOE Integrated Technical Information System. It is available to the public as part of the Federal Research in Progress (FEDRIP) data base on the DIALOG information system (a commercial system) for a fee. Some records and data elements appropriate only for DOE use are omitted from the FEDRIP version.

Hardware/Software:

RIP is accessible by any IBM or compatible personal computer or Macintosh equipped with a modem and communications software capable of VT-100 emulation. FEDRIP is available via dial-up to the DIALOG system with a computer, modem, and communications software.

Contact:

Kelly J. Dwyer
DOE/Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(615) 576-9374

DIALOG Information Services
(800) 334-2564

✍ C.20 RREL TREATABILITY DATA BASE

Sponsoring Agency:

U.S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
Cincinnati, OH

Description of Services:

The RREL Treatability Data Base provides a thorough review of the effectiveness of proven treatment technologies in the removal or destruction of chemicals from media such as municipal and industrial wastewater, drinking water, groundwater, soil, debris, sludge, and sediment. The data base includes only those technologies that are commercially available. The data base is distributed to federal, state, and local governments; foreign governments; academia; industry; and many other groups.

Data:

Version 5.0 of the data base was released in May 1993 and contains 1207 compounds and 13,500 treatability data sets. The data base is organized by chemical. For each compound, the data base includes:

- Physical/chemical properties.
- Freundlich isotherm data.
- Aqueous and solid treatability data.
- Scale (bench, pilot, or field).
- Average concentration of contaminants in influent and effluent.
- Average percentage of removal.
- Reference citations with a reference abstract.

Access:

The data base is available for free upon request. To obtain a diskette copy of the system, send a written request or fax to the contact listed below. Please indicate the disk size (5 ¼ HD or 3 ½ HD) you prefer. The system is also searchable online through ATTIC (see page G-11) and is downloadable from CLU-IN (see page D-14).

Hardware/Software: The Data Base is a standalone menu driven system that runs on an IBM PC or compatible using DOS 2.0 to 6.0. The system requires 7 megabytes of hard disk space and 640 kilobytes or RAM.

Contact:

Glenn M. Shaul
EPA/RREL
26 West Martin Luther King Dr.
Cincinnati, OH 45268
(513) 569-7408
FAX (513) 569-7787

✍ C.21 SOIL TRANSPORT AND FATE DATA BASE AND MODEL MANAGEMENT SYSTEM

Sponsoring Agency:

U.S. Environmental Protection Agency
Robert S. Kerr Environmental Research Laboratory
Ada, OK

Description of Services:

The Soil Transport and Fate (STF) Data Base Version 2.0 presents quantitative and qualitative information concerning the behavior of organic and inorganic chemicals in soil. The STF Data Base provides users with recent information on chemical properties, toxicity, transformation, and bioaccumulation for hundreds of chemical compounds. It can be used by environmental managers, scientists, and regulators working on problems related to vadose zone contamination and remediation.

Data:

The software consists of three major components: the STF Data Base; the Vadose Zone Interactive Processes (VIP) Model and Regulatory and Investigative Treatment Zone (RITZ) Model; and the VIP and RITZ model editors. The data base includes approximately 400 chemicals identified by chemical name (as referenced in 40CFR Part 261), the Chemical Abstract Service (CAS) number, and the common chemical name. The VIP and RITZ models are one-dimensional models that are used in predicting the fate and transport of hazardous organic constituents in the vadose zone. The VIP and RITZ model editors aidin the creation of input files for the respective models and are designed to interface with the STF Data Base.

Access:

Users can obtain a copy of the system and user manual by sending six pre-formatted diskettes (360K minimum) to the address listed below.

Hardware/Software:

The hardware/software requirements for the STF Data Base and Model Management System are:

- IBM-compatible computer
- 640K RAM
- Math coprocessor (for VIP and RITZ models only)
- 12.5 megabytes of hard disk space

Contact:

David S. Burden
Center for Subsurface Modeling Support
EPA/RSKERL
Environmental Research Laboratory
P.O. Box 1198
Ada, OK 74820
(405) 332-8800

✍ C.22 TECHNOLOGY INTEGRATION SYSTEM SUPPORT (TISS)

Sponsoring Agency:

U. S. Department of Energy
Office of Environmental Restoration and Waste Management
Washington, DC

Description of Services:

This system supports DOE in the development of new environmental technologies by providing a central focus for information exchange between DOE and industry, other federal agencies (OFAs), and universities.

Data:

Includes DOE Environmental Technologies, DOE Technology Needs, DOE Documents, DOE Procurement Activities, Vendor Information, Requestor Data Base, and DOE Points of Contact.

Access:

Call DOE-HQ central point of contact at Environmental Technology Information Service to provide information or request information. DOE transmits the request to Oak Ridge Information Center, which provides the requested information. An information packet is prepared and mailed in response to the request.

Hardware/Software:

NextStep system using object oriented, multitasking knowledge base on a 486 platform.

Contact:

Richard Machanoff
Project Manager, HAZWRAP
Martin Marietta Energy Systems, Inc.
(615) 435-3173

DOE Environmental Technology Information Service
(800) 845-2096

✍ C.23 WASTE MANAGEMENT INFORMATION SYSTEM

Sponsoring Agency: U.S. Department of Energy
Oak Ridge, TN

Description of Services: The Waste Management Information System (WMIS) is a dynamic system currently being developed as a management and planning tool. The system provides an accurate and complete resource for information pertaining to waste streams and treatment, storage, and disposal facilities throughout the DOE complex. WMIS in its present form is populated with mixed, hazardous, and radioactive waste data from the various DOE sites. As DOE's primary waste management information system, WMIS supports a variety of DOE programs as well as customizing reports to meet the needs of specific projects. During FY 1993, WMIS was migrated from a VAX 8700 mainframe to a microcomputer-based environment.

Data: The data exists in two major areas:

- Treatment, storage, and disposal (TSD) Capabilities—a compilation of DOE facilities, both existing and planned, for the treatment, storage, and disposal of waste. Storage capabilities, capacities, and information on types of acceptable feedstocks are included. Treatment and disposal methodologies are presented with operating parameters and restrictions.

- Waste Profiles—data on the various wastestreams that have been identified for waste management activities. Data includes generation rates, quantities, characterization, point of contact information, and applicable waste management options.

The data in the two areas presented above are being merged through an artificial link that enables the user to determine which waste profiles or wastestreams are managed at the facilities listed in the TSD Capabilities.

Access: Direct access to the system is available at DOE Headquarters.

Hardware/Software: The data base resides on a Novel local area network and applications are written in FoxPro.

Contact: Lise Wachter, HAZWRAP
Martin Marietta Energy Systems, Inc.
P.O. Box 2003, MS-7606
Oak Ridge, TN 37831-7606
(615) 435-3281

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✍ C.24 U.S. ARMY ENVIRONMENTAL HOTLINE

Primary Contact:	Commander
Address:	U.S. Army Environmental Center Attn: SFIM-AEC-ECS (Environmental Hotline) Aberdeen Proving Ground, MD 21010-5401
Telephone:	Continental U.S.: 1-800-USA-EVHL Outside the Continental U.S.: DSN 584-1699
Hours:	8:00 a.m. - 4:30 p.m. Monday - Friday
Description of Services:	The Army's Environmental Hotline is a comprehensive source for environmental information, including hazardous waste management regulations, forms, training requirements, or any other environmental concerns or questions.
Primary Focus:	The hotline is available to all Department of Army employees worldwide, soldier or civilian, active or reserve component.

✍ C.25 CENTER FOR ENVIRONMENTAL RESEARCH INFORMATION (CERI)

Primary Contact:	Dorothy Williams
Address:	U.S. Environmental Protection Agency Center for Environmental Research Information (CERI) 26 West Martin Luther King Drive Cincinnati, OH 45268
Telephone:	(513) 569-7562 (CML) (8) 684-7562 (FTS)
Fax:	(513) 569-7566 (CML) (8) 684-7566 (FTS)
Hours:	8:00 a.m. - 4:30 p.m. Monday - Friday
Description of Services:	CERI is the focal point for the exchange of scientific and technical environmental information produced by EPA. It supports the activities of the Office of Research and Development (ORD), its laboratories, and associated programs nationwide.
Primary Focus:	CERI's technical information components are responsible for the production and distribution of scientific and technical reports, and for responding to requests for publications. CERI publishes brochures, capsule and summary reports, handbooks, newsletters, project reports, and manuals. Services are provided to EPA employees; federal, state, and local agencies; businesses; and the public.

✍ C.26 DEFENSE TECHNICAL INFORMATION CENTER (DTIC)

Primary Contact:

Address: Defense Technical Information Center
Building 5, Cameron Station
Alexandria, VA 22304-6145

Telephone: (703) 274-3848
DSN 284-3848
1-800-225-3842

Fax: (703) 274-9274

Description of Services: The Defense Technical Information Center (DTIC) is the central point within the Department of Defense (DOD) for acquiring, storing, retrieving, and disseminating scientific and technical information (STI) to support the management and conduct of DOD research, development, engineering, acquisition planning, and studies programs. DTIC's governing regulation is DOD Directive 3200.12, DOD Scientific and Technical Information Program. To carry out its mission, DTIC pursues a program for applying advanced techniques and technologies to DOD STI systems to improve services and information transfer effectiveness.

Primary Focus: DTIC's collection includes topics normally associated with Defense research, such as aeronautics, missile technology, space technology, navigation, and nuclear science. Because DOD's interests are widespread, such subjects as biology, chemistry, energy, environmental sciences, oceanography, computer sciences, sociology, and human factors engineering are also included. DTIC services are available to DOD and its contractors and to other U.S. Government agencies and their contractors.

✍ C.27 GOVERNMENT PRINTING OFFICE (GPO)

Primary Contact:	Superintendent of Documents
Address:	U.S. Government Printing Office Washington, DC 20402
Telephone:	(202) 783-3238 (CML)
Fax:	(202) 275-0019 (CML) (Subscriptions Only) (202) 275-2529 (Inquiries/Orders)
Telex:	(710) 822-9413 (International)
Hours:	8:00 a.m. - 5:00 p.m. Monday - Friday
Description of Services:	The mission of the GPO is the production or procurement of printing for Congress and the agencies of the federal government. GPO also disseminates information to the public through the Superintendent of Documents publications, sales, and depository library programs. Through its documents program, GPO disseminates what is possibly the largest volume of informational literature in the world. The Superintendent of Documents offers approximately 17,000 titles to the public at any given time. These are sold principally by mail order and through a series of bookstores across the country.
Primary Focus:	GPO's primary mandate is to facilitate the printing of Congressional work in an efficient and cost-effective manner. The *Congressional Record* and *Federal Register* are printed daily. Although often referred to as the "Nation's largest publisher," the Superintendent of Documents neither initiates nor exercises control over the publications GPO sells. Virtually all government publications are issued by Congress and the various government agencies. GPO prints or procures the printing of these publications and distributes them through its sales and/or depository programs.

✍ C.28 NATIONAL CENTER FOR ENVIRONMENTAL PUBLICATIONS AND INFORMATION

Primary Contact: National Center for Environmental Publications and Information (NCEPI)

Address: 11029 Kenwood Road, Building 5
Cincinnati, OH 45242

Fax: (513) 891-6685

Description of Services: The National Center for Environmental Publications and Information is the primary national large volume publications distribution clearinghouse for the EPA. More than 4,000 different Agency documents and publications are contained in NCEPI and more than 800,000 documents are distributed monthly to domestic and international destinations.

Primary Focus: The Center for Environmental Research Information (CERI), is NCEPI's largest client. They support the activities of the Office of Research and Development (ORD), its laboratories, and associated programs nationwide. CERI takes publication requests directly through the NCEPI system (an automated inventory and ordering system), which draws down from their inventory and provides a mailing slip through NCEPI which prints that evening. The publication/s are packaged and shipped the next day. CERI also accepts phone, written, and fax requests which are collected and forwarded to NCEPI for processing.

✍ C.29 NATIONAL TECHNICAL INFORMATION SERVICE (NTIS)

Primary Contact:

Address:	National Technical Information Service (NTIS) Springfield, VA 22161
Telephone:	(800) 336-4700 (703) 487-4650 (CML) (703) 487-4639 (TDD)
Fax:	(703) 321-8547 (CML)
Telex:	89-9405 (Domestic) 64617 (International)
Hours:	8:30 a.m. - 5:30 p.m. Monday - Friday
Description of Services:	NTIS, an agency of the U.S. Department of Commerce, is the central source for the public sale of U.S. and foreign government-sponsored research, development, engineering, and business reports. NTIS manages the Federal Computer Products Center, which provides access to software datafiles and data bases by federalagencies.
Primary Focus:	Technical and nontechnical information from government agencies with a heavy emphasis on the publications of the Departments of Commerce, Defense, Energy, Health and Human Services, NASA, and the Environmental Protection Agency. NTIS provides archival service for all of its publications. The primary audience of NTIS is the business and scientific community. Services are also available to the general public, libraries, and educational and environmental groups.

✍ C.30 OFFICE OF RESEARCH AND DEVELOPMENT (ORD) BULLETIN BOARD

Primary Contact: Denis Lussier

Address: U.S. Environmental Protection Agency
Environmental Control Systems Staff
Cincinnati, OH 45268

Telephone: (513) 569-7354 (CML)
(8) 684-7354 (FTS)

Fax: (513) 569-7566 (CML)
(8) 684-7566 (FTS)

Description of Services: The Bulletin Board System (BBS) is designed to facilitate the exchange of technical information and ORD products. The title, publication number, an abstract, author, performing organization, and the availability of the product are included in the Bulletin Board.

Primary Focus: The BBS offers an electronic message system, brief bulletins with information about ORD products and activities, and an online data base for identifying ORD publications. All EPA employees, other federal agencies, states, universities, industry, and the public may access the system.

✍ C.31 OFFICE OF RESEARCH AND DEVELOPMENT ELECTRONIC BULLETIN BOARD SYSTEM (ORD BBS)

Primary Contact:	Jose Peres (513) 569-7272 (CML) (8) 684-7272 (FTS)
Address:	U.S. Environmental Protection Agency Center for Environmental Research Information 26 West Martin Luther King Drive Cincinnati, OH 45268
Telephone:	(513) 569-7610 (CML) (8) 684-7610 (FTS)
Fax:	(513) 569-7566 (CML)
Hours:	24-hour-a-day access to ORD BBS
Description of Services:	The ORD BBS is an online, text-searchable data base of every ORD publication produced since 1976 (more than 15,000 citations). Each citation includes title, authors, abstract, ordering information, and much more. The ORD BBS also offers such features as messages, bulletins of new information, public domain files, and online registration for ORD meetings, and currently has five specialty areas, such as water, regional operations, expert systems, biotechnology, and quality assurance/quality control (QA/QC).
Primary Focus:	The ORD BBS is open to everyone with immediate access to its communication and technology transfer features.

✍ C.32 PUBLIC INFORMATION CENTER (PIC)

Primary Contact:	Kevin Rosseel, Director Alison Cook, Manager
Address:	U.S. Environmental Protection Agency Public Information Center, PM-211B 401 M Street, SW Washington, DC 20460
Telephone:	(202) 475-7751 (CML) (8) 475-7751 (FTS)
Fax:	(202) 382-7883 (CML) (8) 382-7883 (FTS)
Hours:	8:00 a.m. - 5:30 p.m. Monday - Friday
Description of Services:	PIC is the primary point of communication between EPA and the public, and responds to more than 5,000 requests per month on all major environmental topics. In addition, PIC acts as a referral center, directing requests for technical information to appropriate offices, both inside and outside EPA.
Primary Focus:	Examples of documents available at PIC are brochures on EPA programs, factsheets and pamphlets on environmental topics, consumer guides, educational materials, and other nontechnical consumer-oriented information about the environment and EPA.

✍ C.33 TECHNICAL ASSISTANCE DIRECTORY

Primary Contact:	Dorothy Williams
Address:	U.S. Environmental Protection Agency Center for Environmental Research Information (CERI) ORD Publications Unit Cincinnati, OH 45268
Telephone:	(513) 569-7369 (CML) (8) 684-7369 (FTS)
Fax:	(513) 569-7566 (CML) (8) 684-7566 (FTS)
Hours:	8:00 a.m. - 4:30 p.m. Monday - Friday
Description of Services:	The programs, areas of expertise, and primary contacts in each of the major ORD operations are conveyed in this directory.
Primary Focus:	The information is provided to improve communication and technology transfer and is useful for the environmental community, other federal agencies, and individuals who need to locate specific programs within ORD.

✍ C.34 TECHNOLOGY TRANSFER NEWSLETTER

Primary Contact:	Dorothy Williams
Address:	U.S. Environmental Protection Agency Center for Environmental Research Information (CERI) ORD Publications Unit Cincinnati, OH 45268
Telephone:	(513) 569-7369 (CML) (8) 684-7369 (FTS)
Fax:	(513) 569-7566 (CML) (8) 684-7566 (FTS)
Description of Services:	Published semiannually, this document lists titles and descriptions of printed publications that are available from CERI.
Primary Focus:	The newsletter provides interested parties with access to the broad range of currently available technology transfer documents produced by the Office of Research and Development (ORD).

Technology cost or performance is affected by waste characteristics and operating conditions. Because the relevant factors are technology-specific, the most important parameters are identified for each technology. These parameters should be documented, if possible, during report preparation and can serve as guidance for determining a field sampling program during site remediation.

The selected parameters for matrix characteristics and technology operation are shown in Tables D-1 and D-2, respectively. These parameters were developed based on information in scientific literature and from technical judgment. These parameters can serve as a "*base level*" of data that is desirable to evaluate the performance of a technology across sites or from one application to the next. The matrix characteristics can be valuable in assessing the applicability of results from the completed project to other potential sites.

TABLE D-1
MATRIX CHARACTERISTICS AFFECTING TREATMENT COST AND PERFORMANCE[a]

Matrix Characteristics	In Situ Soil Remediation				Ex Situ Soil Remediation					Groundwater Remediation		
	Bio-venting	Fluid Cycling Biorem.	Flush.	SVE	Land Treat.	Compost	Slurry Phase Biorem.	Soil Wash	Thermal Desorp.	In Situ Biorem.	Sparging	Pump/ Treat
Clay Content	✍	✍	✍	✍	✍	✍		✍			✍	✍
Cation Exchange Capacity			✍					✍[b]				
Hydraulic Conductivity		✍	✍							✍	✍	✍
Moisture Content	c	c	✍	✍	c	c	c		✍			✍
Nutrient Content	c	c			c	c	c					
Oxygen Content	c	c			c	c	c			c		
Particle Size Distribution	✍	✍	✍	✍	✍	✍	✍	✍[d]	✍		✍	✍
Permeability	c	c	✍	✍	c	c				✍	✍	✍
pH	✍	✍	✍		✍	✍	✍	✍	✍	✍		
Porosity	✍		✍	✍							✍	✍
Biological Inhibitors	✍	✍			✍	✍	✍			✍		
Redox Potential	c	c			c							
Respirometry Test	✍	✍			✍	✍	✍			✍		
Temperature	c	c			c	c	c			c		
Total Organic Carbon	✍	✍	✍	✍	✍	✍	✍			✍		
Oil and Grease or Total Petroleum Hydrocarbons			✍	✍				✍	✍			✍
Miscellaneous					e				e			

[a]The measurement and reporting of these parameters are desirable to fully characterize an untreated *matrix*. These parameters were selected based on information in the technical literature and on best technical judgment because they are considered to be the major matrix characteristics that affect cost or treatment performance. The types and properties of contaminants are important for all treatment technologies, and are described separately. Geologic and hydrogeologic assessments are important for all in situ treatment technologies and are described separately.
[b]Cation exchange capacity is an important matrix characteristic for soil washing of metal-containing wastes.
[c]Moisture content, nutrient content, oxygen content, permeability, and redox potential are important parameters for biotreatment technologies and are accounted for in the table of operating parameters.
[d]The particle size distribution-contaminant relationship is an important matrix characteristic for soil washing.
[e]Miscellaneous matrix characteristics include field capacity for land treatment; bulk density and lower explosive limit for thermal desorption.

TABLE D-2
OPERATING PARAMETERS AFFECTING TREATMENT COST AND PERFORMANCE[a]

Operating Parameters	In Situ Soil Remediation				Ex Situ Soil Remediation					Groundwater Remediation		
	Bio-venting	Fluid Cycling Biorem.	Flush.	SVE	Land Treat.	Compost	Slurry Phase Biorem.	Soil Washing	Thermal Desorp.	In Situ Biorem.	Sparging	Pump/ Treat
Air Flow Rate	✍			✍		✍	✍			✍	✍	
Biomass Concentration/ Microorganism Content	✍	✍			✍	✍	✍			✍		
Mixing Rate/Frequency					b	b	✍					
Moisture Content	✍	✍			✍	✍	✍c	✍c	✍			
Nutrient Demand and Supply Rate	✍	✍			✍	✍	✍			✍		
Operating Pressure/Vacuum	✍			✍							✍	
Oxygen or Other Electron Acceptor Concentration and Supply Rate	✍d	✍			✍	✍	✍			✍		
pH		✍	✍		✍	✍	✍	✍		✍		
Permeability	✍	✍			✍	✍						
Pumping Rate			✍									✍
Redox Potential	✍	✍			✍							
Residence Time					✍	✍	✍		✍			
System Throughput							✍	✍	✍			
Temperature	✍	✍			✍	✍	✍		✍			
Washing/Flushing Solution Components/Additives and Dosage			✍					✍				

[a]The measurement and reporting of these parameters are desirable to fully evaluate the *treatment operation*. These parameters were selected based on information in the technical literature and on best technical judgment because they are considered to be the major factors that affect treatment cost or performance.

[b]Mixing rate/frequency for land treatment refers to tilling and for composting refers to turning.

[c]Solid to liquid ratio is an important parameter for evaluating slurry phase bioremediation and soil washing.

[d]Oxygen utilization or carbon dioxide production is an important parameter for evaluating bioventing.

Appendix E
DESCRIPTION OF SOURCE DOCUMENTS

A list of U.S. Government reports documenting innovative and conventional site remediation technologies that are incorporated into this compendium guide is presented in Table E-1. These documents are described in greater detail below.

TABLE E-1
U.S. GOVERNMENT REMEDIATION TECHNOLOGY REPORTS

Government Sponsoring Agency	Title
U.S. Army Environmental Center (USAEC)	*Installation Restoration and Hazardous Waste Control Technologies,* Third Edition, November 1992
Federal Remediation Technologies Roundtable	*Synopses of Federal Demonstrations of Innovative Site Remediation Technologies,* Third Edition, August 1993. *Accessing Federal Data Bases for Contaminated Site Clean-Up Technologies,* Third Edition, September 1993. *Federal Publications on Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation,* Third Edition, September 1993.
EPA	*The Superfund Innovative Technology Evaluation (SITE) Program: Technology Profiles,* Sixth Edition, November 1993
DOE	*Technology Catalogue,* First Edition, February 1994
USAF, EPA	*Remediation Technologies Screening Matrix and Reference Guide,* Version I, July 1993
USAF	*Remedial Technology Design, Performance, and Cost Study,* July 1992
California Base Closure Environmental Committee	*Treatment Technologies Applications Matrix for Base Closure Activities*, November 1993
EPA/U.S. Navy	*EPA/Navy CERCLA Remedial Action Technology Guide,* November 1993

✍ E.1 INSTALLATION RESTORATION AND HAZARDOUS WASTE CONTROL TECHNOLOGIES (THIRD EDITION, NOVEMBER 1992)

The purpose of this guide is to provide a reference to pertinent and current treatment technologies for public and private sector program managers dealing with installation restoration and hazardous waste control technologies. The third edition

of this handbook was published in 1992 (U.S. Army Corps of Engineers Toxic and Hazardous Materials Agency, Report CETHA-TS-CR-92053, 1992).

The information contained in this handbook was obtained through personal interviews with Army, Navy, Air Force, and EPA personnel directly involved in research, development, and implementation of new and effective methods to accomplish the following: restoration of contaminated soil, groundwater, and structures; and minimization of the generation of hazardous waste materials.

The summaries of specific technologies include:

- The purpose of developing the technology.
- In what cases the technology is applicable.
- A description of the technology.
- Advantages and limitations of the technology with respect to environmental impact.
- Costs associated with implementing the technology.
- Availability of equipment required.
- The current status of development.
- References, including reports, journal articles, and patents; photographs and drawings, if available; and points of contact for additional technical information.

✍ E.2 SYNOPSES OF FEDERAL DEMONSTRATIONS OF INNOVATIVE SITE REMEDIATION TECHNOLOGIES (THIRD EDITION, AUGUST 1993)

This publication (EPA/542/B-93/009) was prepared under the auspices of the Federal Remediation Technologies Roundtable (FRTR). This organization was created to establish a process for applied hazardous waste site remediation technology information exchange, to consider cooperative efforts of mutual interest, and to develop strategies and analyze remedial problems that would benefit from the application of innovative technologies.

This collection of abstracts describes field demonstrations of innovative technologies to treat hazardous waste at contaminated sites. The collection is intended to be an information resource for hazardous waste site project managers who are assessing the availability and viability of innovative technologies for treating contaminated groundwater, soils, and sludge. It also is intended to assist government agencies in coordinating ongoing hazardous waste remediation technology research initiatives, particularly those sponsored by EPA, DOD, DOE, and DOI. Innovative technologies, for the purposes of this compendium, were defined as those for which detailed performance and cost data were not readily available.

The demonstrations discussed in this document were all sponsored by EPA, DOD, DOE, and DOI. In total, 112 demonstrations in six different technology categories are described. These demonstrations involve the use of innovative technologies to treat soil and groundwater. Only federally sponsored studies and demonstrations that have tested innovative remedial technologies with site-specific wastes under realistic conditions as a part of large pilot- or full-scale field demonstrations are included.

✍ E.3 ACCESSING FEDERAL DATA BASES FOR CONTAMINATED SITE CLEAN-UP TECHNOLOGIES

The FRTR developed this publication (EPA/542/B-93/008) to provide information on accessing federal data bases that contain data on innovative remediation technologies. The profiles contained in this edition were identified through a review of reports, articles, and publications by FRTR member agencies and telephone interviews with data base experts. Roundtable members include EPA, DOD, DOE, and DOI. In addition, the National Aeronautics and Space Administration (NASA) participates in FRTR meetings.

This document is a reference tool that provides information on those systems maintaining data on remedial technologies. It may be used by project managers as a pointer to repositories of technical information, or as a source of contacts that may be useful to future system design. Each data base profile contains information on data elements, system uses, hardware and software requirements, and access. The profiles also contain contacts for each system. A matrix showing system characteristics of the data bases and a table summarizing information contained in the data base profiles are provided.

✍ E.4 FEDERAL PUBLICATIONS ON ALTERNATIVE AND INNOVATIVE TREATMENT TECHNOLOGIES FOR CORRECTIVE ACTION AND SITE REMEDIATION

The FRTR has prepared this bibliography (EPA/542/B-93/007) to publicize the availability of federal documents pertaining to innovative and alternative technologies to treat hazardous wastes. This updated edition contains references for documents and reports from EPA, the U.S. Army, the U.S. Navy, the USAF, DOE, and DOI. The FRTR obtained this reference information from a variety of sources:

- Federal agency report, project, and publication lists from EPA, the Naval Civil Engineering Laboratory, USAEC, the U.S. Army Engineer Waterways Experiment Station, the USAF Engineering and Sciences Center, DOE, and DOI.

- The National Technical Information Service (NTIS) and other data bases.

This bibliography addresses technologies that provide for the treatment of hazardous wastes; therefore, it does not contain information or references for containment or other nontreatment strategies, such as landfilling and capping. This bibliography emphasizes innovative technologies for which detailed cost and performance data are not readily available. Information on more conventional

treatment technologies, such as incineration and solidification, is not included.

In addition to improving access to information on innovative technologies, FRTR 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 as a starting point in pursuit of information on innovative alternative hazardous waste treatment technologies and has been included, whole, in Section 5, References.

✍ E.5 THE SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION (SITE) PROGRAM: TECHNOLOGY PROFILES (SIXTH EDITION, NOVEMBER 1993)

The SITE Program evaluates new and promising treatment and monitoring and measurement technologies for cleanup of hazardous waste sites. The program was created to encourage the development and routine use of innovative treatment technologies. As a result, the SITE Program provides environmental decision-makers with data on new, viable treatment technologies that may have performance or cost advantages compared to traditional treatment technologies.

This document, prepared between June 1993 and October 1993, was intended as a reference guide (EPA/540/R-93/526) for those interested in technologies under the SITE Demonstration, Emerging Technology, and Monitoring and Measurement Technologies Programs. The two–page profiles, which are organized into two sections (completed and ongoing projects) for each program, are presented in alphabetical order by developer name. Each technology profile contains:

- A technology developer and process name.
- A technology description, including a schematic diagram or photograph of the process.
- A discussion of waste applicability.
- A project status report.
- EPA project manager and technology developer contacts.
- A schematic diagram or photograph of the process.

The profiles also include summaries of demonstration results if available. The technology description and waste applicability sections are written by the developer. EPA prepared the status and demonstration results sections.

Reference tables for SITE Program participants precede the sections and contain EPA and developer contacts. The tables present both waste and media categories. The waste categories include specific chemicals or chemical groups. The following media categories are considered: air/gases, groundwater/liquids, leachate, sediment, sludge, soil, solid debris, and wastewater.

✍ E.6 TECHNOLOGY CATALOGUE (FIRST EDITION, FEBRUARY 1994)

The DOE *Technology Catalogue* features technologies successfully demonstrated in the field and sufficiently mature to be used in the near future. Technologies to address the following are presented in the catalogue:

- Buried waste.
- Mixed waste landfill.
- Underground storage tank (UST).
- Volatile organic compound (VOC) contamination in arid soil.
- VOC contamination in non-arid soil.

Several methodologies were employed to select and prepare technology profiles. Factors affecting the selection of technologies included the availability and quality of technical information and the maturity of the technology. The primary source of information for the catalogue was the ProTech Prospective Technology Database developed by Battelle Seattle Research Center for DOE. ProTech is a prototype electronic system including innovative technologies that are part of integrated demonstrations. Additional sources of information included technical task plans, conference proceedings, technical journals, environmental permit applications, and data supplied by principal investigators.

Technology entries are each two to three pages long and include the following areas:

- Technology title and description.
- Technical performance and cost data.
- Projected near-term performance (1 to 3 years).
- Applicable waste types and forms.
- Development status.
- Key regulatory considerations regarding the application of the technology.
- Potential non-DOE applications.
- Baseline comparison technology.
- Intellectual property rights.
- Points-of-contact (POCs) and references for more information.

A summary of the technologies presented in this document, organized by contaminant applicability, is presented in Appendix B.

✍ E.7 REMEDIATION TECHNOLOGIES SCREENING MATRIX AND REFERENCE GUIDE (VERSION I, JULY 1993)

This U.S. Air Force (USAF)/EPA document (EPA/542/B-93/005) provides information to help site RPMs narrow the field of remediation alternatives and identify potentially applicable technologies for more detailed assessment prior to remedy selection.

Forty-eight technologies, including in situ and ex situ biological, thermal, and physical/chemical processes, are included. In addition to treatment technologies, processes designed to be used primarily for containment, waste separation, and enhanced recovery have been included to provide a broad range of remedial options.

The technologies presented in the matrix are evaluated in relation to 13 factors that address specific cost, performance, and technical, developmental, and institutional issues. These screening factors were chosen to assist RPMs in identifying applicable technologies for media and contaminants of concern at their sites.

This document was developed with extensive input from technical experts, including professionals representing all segments of the remediation community, site remediation technology researchers, technology developers, and technology users from federal agencies, state governments, universities, and the private sector.

More than 30 experts participated in an intensive workshop on 2-3 March 1993, at Tyndall Air Force Base, Florida. Based on their collective experience and expertise, they selected appropriate technologies and processes to be included in the matrix, identified the contaminant groups addressed by each technology, and developed the list of factors against which the technologies were evaluated. Workshop participants then separated into three small groups and focused on the technologies in their individual areas of specialization (biological processes, thermal processes, and physical/chemical processes) to develop the ratings for each of the technologies shown in the matrix. Each technical expert had the opportunity to review draft documents independently and provide written comments.

Two appendices provide additional information. Appendix A contains a list of reference materials, including field demonstration reports and case studies, that RPMs may wish to consult for more detailed information about various technologies. Appendix B lists examples of contaminants included in each contaminant group used in the matrix.

✍ E.8 REMEDIAL TECHNOLOGY DESIGN, PERFORMANCE, AND COST STUDY (JULY 1992)

The purpose of this USAF study was to provide a technical reference for USAF engineers and project managers on the state-of-the-art for established remedial technologies likely to be used at USAF installations. For purposes of this report, established technologies were defined as those involved in more than 100 remediation projects so that information about design, performance, and cost would be available for a variety of environmental conditions. The technologies reviewed in this study included bioremediation, air stripping, vacuum extraction, thermal treatment, carbon adsorption, stabilization and solidification, and contaminant recovery and separation.

This independent source of information supports the review of USAF contractor activities, including reviews of feasibility studies identifying a preferred remedial strategy, cost estimates and proposals for site remediation, and designs for remedial equipment and systems.

A second purpose of this study was to obtain information from vendors about their experience in selecting remedial technologies and developing strategies for their implementation. Such information provides additional substance on which USAF engineers can base decisions for remedial actions at USAF sites.

More than 200 vendors were contacted for information. Site visits were conducted with 35 vendors who had extensive experience with at least one of the remedial technologies in order to elicit detailed information on equipment design, performance, cost, and technology selection and implementation.

✍ E.9 TREATMENT TECHNOLOGIES APPLICATIONS MATRIX FOR BASE CLOSURE ACTIVITIES (NOVEMBER 1993)

The *Treatment Technologies Applications Matrix for Base Closure Activities* was prepared as a collaborative effort by representatives of the USAF Center for Environmental Excellence; USACE; U.S. Navy, WESTDIV; DOE; EPA, Region IX; California State Water Resources Control Board; and the Department of Toxic Substances Control.

A result of a 23-25 June 1992 base closure meeting in Sacramento, California, was a recommendation to develop a means for the transfer of treatment technology information currently available and applicable to Installation Restoration Program (IRP) sites at federal facilities. The California Military Base Closure Environmental Committee addressed this issue by forming a Process Action Team (PAT) to identify and evaluate (1) existing data regarding contaminant problems common to base closure facilities and (2) treatment technologies associated with those problems that have proven effective. The matrix was developed by the PAT to facilitate identification of potentially applicable treatment technologies that should be considered for hazardous waste site cleanup.

The matrix identifies the major categories of contaminants and contaminated media found at these sites and lists the treatment technologies that may be applicable. In addition to listing the technologies for each of the contaminant types, the matrix provides information on each technology, including advantages, technology restrictions, California sites where the technology is used, contacts with extensive knowledge of the technology, general comments, and references. Supporting documentation also includes a description of typical problem areas and the contaminants found at these sites. Comments on advantages and restrictions for each technology are noted in the matrix by references to the attached sections listing technology advantages and restrictions.

✍ E.10 EPA/NAVY CERCLA REMEDIAL ACTION TECHNOLOGY GUIDE (NOVEMBER 1993)

The *EPA/Navy CERCLA Remedial Action Technology Guide* is a collection of (1) engineering bulletins produced by EPA's Technical Support Branch in Cincinnati, Ohio, and (2) remedial action technical data sheets produced by the Naval Energy and Environmental Support Activity (NEESA) in Port Hueneme, California. These documents comprehensively summarize the latest information obtainable on many of the best available remedial technologies. The intent is to convey information (based on previous applications) to help RPMs, engineers in charge, on-scene coordinators, Navy resident officers in charge of construction, and contractors decide if a technology should be used at a hazardous waste site and, if so, what are the relevant design, implementation, and cost considerations. Addenda will be issued periodically to update the original bulletins and technical data sheets, and other technologies may be added.

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FOLD OUT MATRIX

Coming from Graphics

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Treatment Technologies Screening Matrix

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