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FOREWORD

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The Federal Remediation Technology Roundtable (FRTR) was established in 1991 as an interagency committee to exchange information and to 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. Publication of remediation information on the Internet has added a new dimension to the amount of information accessible to the RPM. To assist the RPM in the evaluation process and to enhance technology transfer among Federal agencies, we developed this website to combine the unique features of several agency publications into a single website with extensive links to other remediation technology websites. 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. FRTR member agencies plan to frequently update this website to help the RPM keep pace with the ever-changing range of technologies available.

U.S. Army Environmental Center	U.S. Environmental Protection Agency Technology Innovation Office
U.S. Army Corps of Engineers Hazardous Toxic and Radioactive Waste Center of Expertise	U.S. Environmental Protection Agency National Risk Management Research Laboratory
U.S. Air Force Center for Environmental Excellence	U.S. Department of Energy Environmental Management
U.S. Naval Facilities Engineering Service Center	U.S. Geological Survey
Federal Remediation Technologies Roundtable	Interstate Technology Regulatory Cooperation

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and/or evaluation of 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 also included.

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This reference guide is the product of a cooperative effort between the member agencies of the Federal Remediation Technologies Roundtable (FRTR). Platinum International, Inc. prepared the text and graphics under Army Contract DACA31-99-D-0045. The Army contract project officers were Scott Hill and Richard Williams of the U.S. Army Environmental Center, Pollution Prevention, Compliance, Acquisition and Technology Division. Julie Van Deuren served as the PII Project Manager and Teressa Lloyd, Shobha Chhetry, Raycharn Liou, James Peck as principal authors.

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The following reviewers each contributed to the depth of this report through comments based on their considerable expertise:

Mr. Scott Hill U.S. Army Environmental Center 5179 Hoadley Road Bldg. E-4430 SFIM-AEC-PCT APG, MD 21010-5401 FAX: 410-436-6836 E-mail: Scott.Hill@aec.apgea.army.mil	Mr. Richard Williams U.S. Army Environmental Center 5179 Hoadley Road Bldg. E-4430 SFIM-AEC-PCT APG, MD 21010-5401 FAX: 410-436-6836 E-mail: Richard.Williams@aec.apgea.army.mil
Mr. Marty Kushner Interstate Technology Regulatory Cooperation (ITRC) 444 North Capitol Street N.W. Suite 445 Washington D.C. 20001 FAX: 202-624-3666 E-mail: mkushner@sso.org	Mr. Tanwir Chaudhry Intergraph Corp Naval Facilities Engineering Service Center Attn: ESC411 1100 23rd Avenue Port Hueneme, CA 93043-4370 FAX: 805-982-5623 E-mail: chaudhryt@nfesc.navy.mil
Mr. Robert Nash Naval Facilities Engineering Service Center Attn: ESC414RN 1100 23rd Avenue Port Hueneme, CA 93043-4370 FAX: 805-982-4304 E-mail: nashra@nfesc.navy.mil	Ms. Beth Moore U.S. Department of Energy (DOE/EM-52) Environment Management Science Program Forrestal Building, Room 3E066 1000 Independence Avenue S.W. Washington, D.C. 20585 FAX: 202-586-1492 E-mail: beth.moore@em.doe.gov
Ms. Johnette Shockley U.S. Army Corps of Engineers HTRW-CX 12565 West Center Road Omaha, NE 68144 FAX: 402-697-2595 E-mail: johnette.c.shockley@usace.army.mil	Mr. Richard J. Weisman Tetra Tech EM Inc. 1881 Campus Commons Dr., Suite 200 Reston, VA 20191 FAX: 703-391-5876 E-mail: richard.weisman@ttemi.com
Mr. Rick Tomlinson Interstate Technology Regulatory Cooperation (ITRC) 444 North Capitol Street N.W. Suite 445 Washington D.C. 20001 FAX: 202-624-3666	Mr. John Powell U.S. Geological Survey 12201 Sunrise Valley Drive (MS414) Reston, VA 20192 FAX: 703- 648-5722 E-mail: jdpowell@usgs.gov

E-mail: rickt@sso.org	
Mr. Ian T. Osgersby PhD, PE U.S. Army Corps of Engineers 696 Virginia Road Concord, MA 01742 FAX: 978-318-8663 E-mail: ian.t.osgersby@usace.army.mil	Mr. Peter J. Shields Tetra Tech EM Inc 1881 Campus Commons Drive, Suite 200 Reston, VA 20191 FAX: 703-391-5876 E-mail: pete.shields@ttemi.com
Mr. John Quander U.S. Environmental Protection Agency Technology Innovation Office 1200 Pennsylvania Avenue, N.W. Suite 5102G Washington D.C. 20460 FAX: 703-603-9135 E-mail: Quander.John@epa.gov	Mr. Jeff Breckenridge U.S. Army Corps of Engineers 12565 West Center Road Omaha, NE 68144 FAX: 402-697-2639 E-mail: jeff.l.breckenridge@usace.army.mil

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Section 1 - Introduction

1.1 Objectives

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The goal of remedial investigation/feasibility studies (RI/FS) and hazardous waste cleanup projects is to obtain enough information on a 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.

This reference guide provides a "yellow pages" of remediation technologies. It 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 reference guide allows the reader to gather essential descriptive information on the respective 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. All levels of remediation technologies are included in this guide. 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.

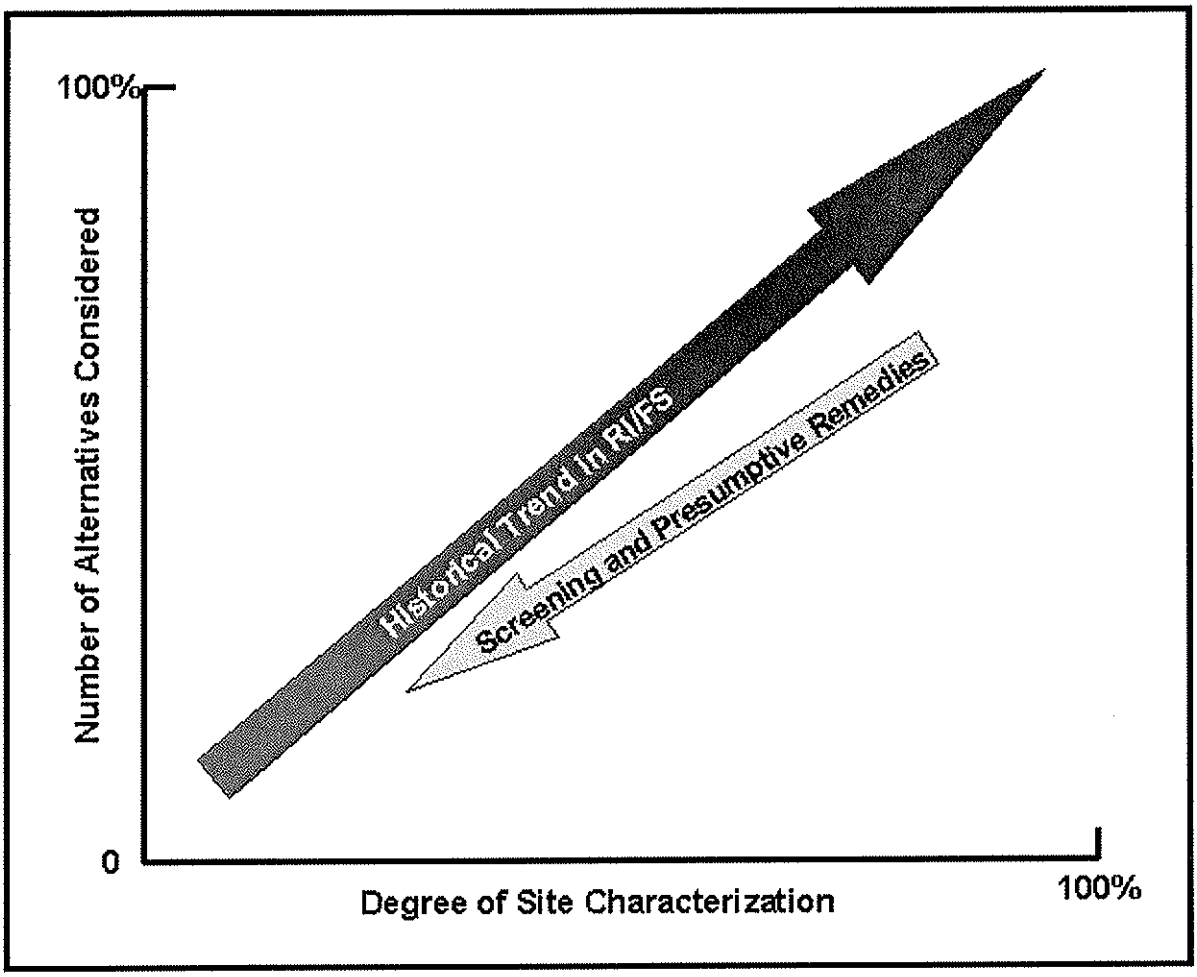

Figure 1-1 Reduction of Data Needs by Screening and Presumptive Remedies

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Section 1 - Introduction

1.2 Background

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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)	Pollution Prevention Environmental Technology Division & Innovative Technology Demonstration, Evaluation and Transfer, USAEC, 2000
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*, Fourth Edition, October 1995 *Federal Publications on Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation*, Fourth Edition, October 1995 *FRTR Remediation Technologies Screening Matrix and Reference Guide*, Version III, November 1997
EPA	*The Superfund Innovative Technology Evaluation (SITE) Program: Technology Profiles*, Tenth Edition, 1999
DOE	*Technology Catalogue*, Second Edition, April 1995
USAF	*Remedial Technology Design, Performance, and Cost Study*, July 1992

California Military Environmental Coordination Committee	*Treatment Technologies Applications Matrix for Base Closure Activities*, Spring 1996
EPA/U.S. Navy	*EPA/Navy CERCLA Remedial Action Technology Guide*, November 1993

1.3 How to Use this Website

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This guide contains five sections:

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

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

Sections 2 through 5 are intended to aid a RPM in performing the RI/FS or equivalent process (see Figure 1-2: The Role of This Document in the RI/FS Process (or Equivalent)).

Section 2, Contaminant Perspectives, addresses contaminant properties, their behavior and preliminarily identification of potential treatment technologies based on their applicability to specific contaminants and media. This section describes eight contaminant groups, as determined by the Federal Remediation Technologies Roundtable (FRTR):

- Nonhalogenated Volatile Organic Compounds (VOCs).
- Halogenated Volatile Organic Compounds (VOCs).
- Nonhalogenated Semivolatile Organic Compounds (SVOCs).
- Halogenated Semivolatile Organic Compounds (SVOCs).
- Fuels.
- Inorganics.
- Radionuclides.
- Explosives.

Remedial technologies capable of treating a contaminant group are presented in a technology screening matrix for each of the eight contaminant groups. The most commonly used technologies are discussed in the text for that contaminant in soil, sediment, and sludge, and in ground water, 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 14 treatment areas:

- In situ biological treatment for soil, sediment, bedrock, and sludge.
- In situ physical/chemical treatment for soil, sediment, bedrock, and sludge.
- In situ thermal treatment for soil, sediment, bedrock, and sludge.
- Ex situ biological treatment for soil, sediment, bedrock, and sludge.
- Ex situ physical/chemical treatment for soil, sediment, bedrock, and sludge.

- Ex situ thermal treatment for soil, sediment,bedrock, and sludge.
- Containment for soil, sediment, bedrock, and sludge.
- Other treatments for soil, sediment, bedrock, and sludge.
- In situ biological treatment for ground water, surface water, and leachate.
- In situ physical/chemical treatment for ground water, surface water, and leachate.
- Ex situ biological treatment for ground water, surface water, and leachate.
- Ex situ physical/chemical treatment for ground water, surface water, and leachate.
- Containment for ground water, 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, 1995 and 2001), and the Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (FRTR, 1993 and 2000).

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.
- Synonyms.
- Applicability.
- Limitations.
- Data needs.
- Performance data.
- Cost.
- References (typically, published public sector reports were extracted from the source documents. References are hyper linked to their specific web sites if HTML version of the documents are available).
- Site information (typically, representative sites with the most complete information were chosen).
- Points of contact (A hyper link to all government agencies' home page is created. Technology specific web sites from government agencies and non-government agencies are also linked if they are available).
- Vendor Information.
- Health and Safety.

Information contained in these profiles was extracted from the source documents, followed by an extensive review by the FRTR member agencies. 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 EPA Remediation and Characterization Innovative Technologies (EPA REACH IT) database.

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 a comprehensive list of references used in this document as well as source documents on innovative treatment technologies sorted by author name. Subsection 5.3 presents a listing of federal agencies, universities, and companies with related technical information available on their Web sites. These Web addresses are sorted by host name along with the technology name.

The six appendices to this document contain the following information:

Appendix A, EPA Remediation and Characterization Innovative Technologies (EPA

REACH IT) database. This appendix provides a brief description of the EPA REACH IT data base and a current printout of the vendors of technologies included in this guide, including the company name and telephone number.

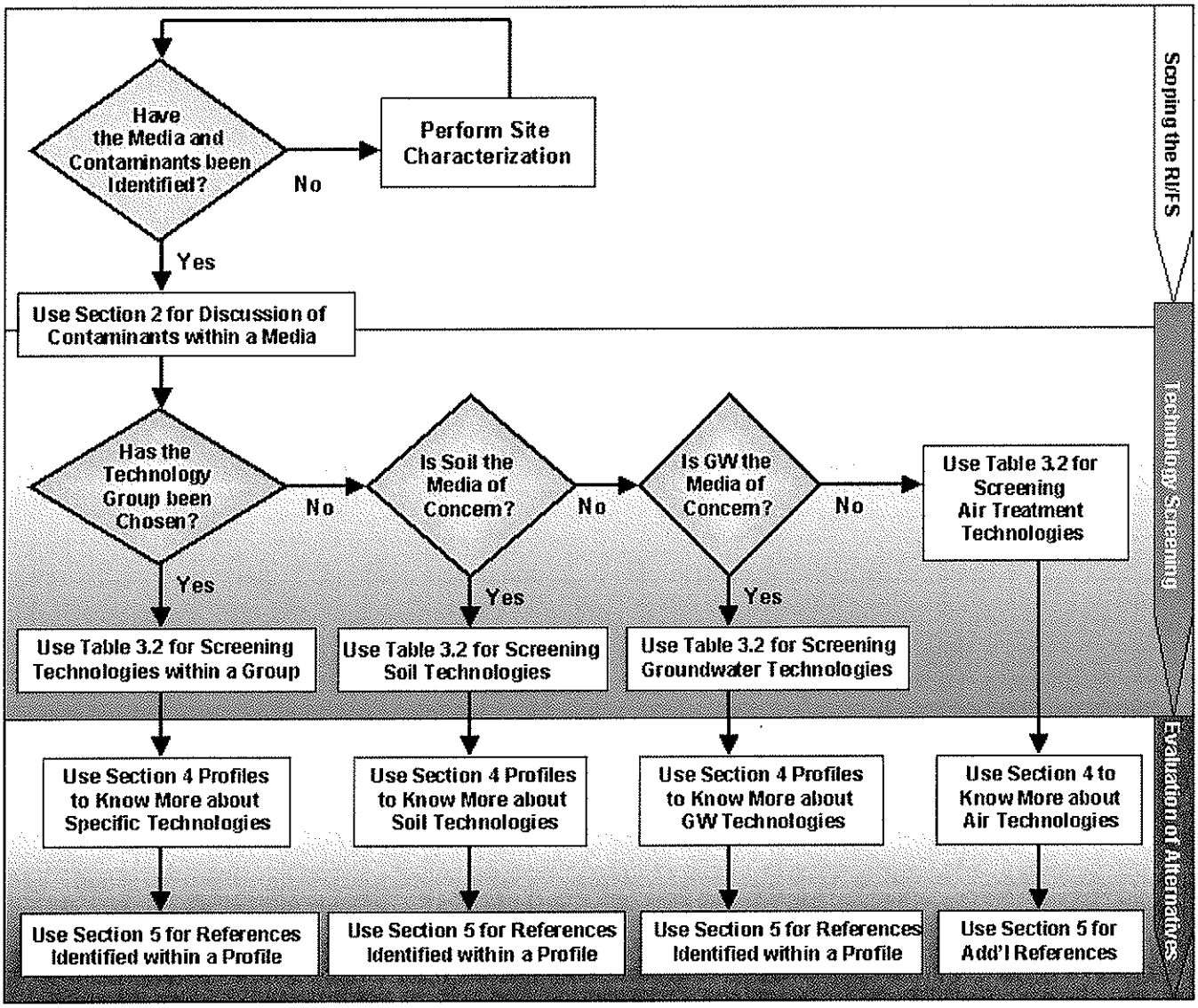
Appendix B, DOE Site Remediation Technologies by Waste Contaminant Matrix and Completed Site Demonstration Program Projects as of October 1993. Table B-1 provides a complete listing of the treatment technologies provided in the DOE Technology Catalogue organized by the contaminant applicability. Table 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 9 December 1998 to review related activities, identify information needs, and develop an updated 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.

Appendix F, Synonym List. Technology names and possible synonyms are listed by alphabetical order. They are linked to their corresponding technology profiles for convenient access.


Scoping the RI/FS
Technology Screening
Evaluation of Alternatives
Have the Media and Contaminants been Identified?
No
Perform Site Characterization
Yes
Use Section 2 for Discussion of Contaminants within a Media
Has the Technology Group been Chosen?
No
Is Soil the Media of Concern?
No
Is GW the Media of Concern?
No
Use Table 3.2 for Screening Air Treatment Technologies
Yes
Use Table 3.2 for Screening Technologies within a Group
Yes
Use Table 3.2 for Screening Soil Technologies
Yes
Use Table 3.2 for Screening Groundwater Technologies
Use Section 4 Profiles to Know More about Specific Technologies
Use Section 4 Profiles to Know More about Soil Technologies
Use Section 4 Profiles to Know More about GW Technologies
Use Section 4 to Know More about Air Technologies
Use Section 5 for References Identified within a Profile
Use Section 5 for References Identified within a Profile
Use Section 5 for References Identified within a Profile
Use Section 5 for Add'l References

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Section 1 - Introduction

1.4 Requirements to Consider Technology's Impacts on Natural Resources

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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 Pollution Act (OPA) require that residual natural resource damages 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. Forest Service, 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.

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Section 1 - Introduction

1.5 Cautionary Notes

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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 1994 through 2000 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.

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Section 2 Introduction: Contaminant Perspectives

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Information on classes and concentrations of chemical contaminants, how they are distributed through out 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 eight contaminant groups as follows:

- Nonhalogenated volatile organic compounds (VOCs).
- Halogenated volatile organic compounds.
- Nonhalogenated semivolatile organic compounds (SVOCs).
- Halogenated semivolatile organic compounds
- Fuels.
- Inorganics.
- Radionuclides.
- 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) ground water, surface water, and leachate. (The nonhalogenated and halogenated VOC contamination sections additionally address 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), the system reliability (better, average, or below average), the cleanup time (long, average, or short) 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, 1994). The applicability rating was determined from information presented in the second edition of this document (FRTR, 1994). These rating codes were reviewed in 1997. **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 FRTR 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 eight contaminant groups appears in Subsections 2.3 to 2.10.

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

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2.1 Presumptive Remedies

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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 presumptive remedy may not be used include unusual site soil characteristics, 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 seven published presumptive remedy documents:

- *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites. Final Guidance* (EPA, 1996). EPA Document No. 540-R-96-023.
- *User Guide to the VOCs in Soils. Presumptive Remedy* (EPA, 1996). EPA Document No. 540-F-96-008.
- *Presumptive Remedy - CERCLA Landfill Caps RI/FS Data Collection Guide* (EPA, 1995). EPA Document No. 540-F-95-009.
- *Presumptive Remedy for Soils, Sediments, and Sludges at Wood Treater Sites* (EPA, 1995). EPA Document No. 540-R-95-128.
- *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 ground water, PCB, coal gas sites, 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 ground water.

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2.2 Data Requirements

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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. This matrix is also an effort by FRTR.

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2.2.1 Data Requirements for Soil, Sediment, Bedrock and Sludge

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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 oil/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 ground water; 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. 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.

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2.2.2 Data Requirements for Ground Water, Surface Water, and Leachate

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It is common for ground water 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 ground water 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 ground water.

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 ground water remediation. A detailed **geologic characterization** is usually needed to assess the uniformity (homogeneity and isotropy) of the subsurface hydrostratigraphy. The average **rate of ground water flow** can be estimated from the hydraulic conductivity, hydraulic gradient, and effective porosity. **Hydraulic gradient** is calculated from ground water 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 ground water extraction system is being planned, **safe aquifer yields** and **boundary conditions** must be established. These parameters require that pumping tests be conducted.

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2.2.3 Data Requirements for Air Emissions/Off-Gases

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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 must be provided 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.

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2.3 NONHALOGENATED VOLATILE ORGANIC COMPOUNDS

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Sites where nonhalogenated 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 nonhalogenated VOCs (excluding fuels, BTEX, and gas phase contaminants) encountered at many sites include the following:

- Nonhalogenated VOCs*

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

*Please note that fuels, BTEX, and gas phase contaminants are located in section 2.7.

Click here, for further information on specific contaminants: Contaminant Specific Web Sites
Click here, for DOE's Preferred Alternatives Matrices (PAMs): PAMs

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2.3.1 Properties and Behavior of Nonhalogenated VOCs

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An important consideration when evaluating a remedy is whether the compound is nonhalogenated or halogenated. A nonhalogenated compound is one which does not have a halogen (e.g., fluorine, chlorine, bromine, or iodine) attached to it. Typical nonhalogenated VOCs have been listed at the beginning of Subsection 2.3.

The vendor of the technology being evaluated must be informed whether the compounds to be treated are nonhalogenated or halogenated. 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 nonhalogenated compounds.

Subsurface contamination by nonhalogenated 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 ground water 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 ground water 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 unity and will tend to sink to the bottom of surface waters and ground water aquifers. Light NAPLs (LNAPLs) will float on top of surface water and ground water. 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.

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

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Soil vapor extraction (SVE), thermal desorption, and incineration are the presumptive remedies for Superfund sites with nonhalogenated 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 nonhalogenated 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 of bioventing 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 more than 145 fuel sites at 56 military installations, including one Marine, three Army, and one Coast Guard facility. Approximately 50% of the current systems are full scale. As of September 1995, approximately 125 is installed and operating. The remainder are to be installed.

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2.3.3 Common Treatment Technologies for Nonhalogenated VOCs in Ground Water, Surface Water and Leachate

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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 ground water. **Treatability studies** to characterize the biodegradability may be needed for any biodegradation technology. Treatability studies are usually necessary to ensure that the contaminated ground water can be treated effectively at the design flow. A **subsurface geologic** characterization would be needed for any isolation or stabilization technologies. **Ground water 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 nonhalogenated VOCs in ground water, surface water, and leachate are air stripping and carbon adsorption. These are both ex situ technologies requiring ground water 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 ground water 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 taken off-site for disposal. Carbon used for explosives- or metals-contaminated ground water must be removed and properly disposed of. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes.

Other fairly common technologies used in separating contaminants from ground water are distillation and membrane pervaporation.

Membrane pervaporation is a process that uses permeable membranes that preferentially adsorb volatile organic compounds (VOCs) from contaminated water. Contaminated water first passes through a heat exchanger, raising the water temperature. The heated water then enters the pervaporation module, containing membranes composed of a nonporous organophilic polymer, similar to silicone rubber, formed into capillary fibers. VOCs diffuse by vacuum from the membrane-water interface through the membrane wall. Treated water exits the pervaporation module, while the organic vapors travel from the module to a condenser where they return to the liquid phase. The condensed organic materials represent only a fraction of the initial wastewater volume and may be subsequently disposed of at a cost savings.

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

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Three technologies that are most commonly used to treat nonhalogenated 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 ° 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 ° 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 °, and gas residence times are typically 1 second or less.

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2.3.5 Common Treatment Train for Nonhalogenated VOCs

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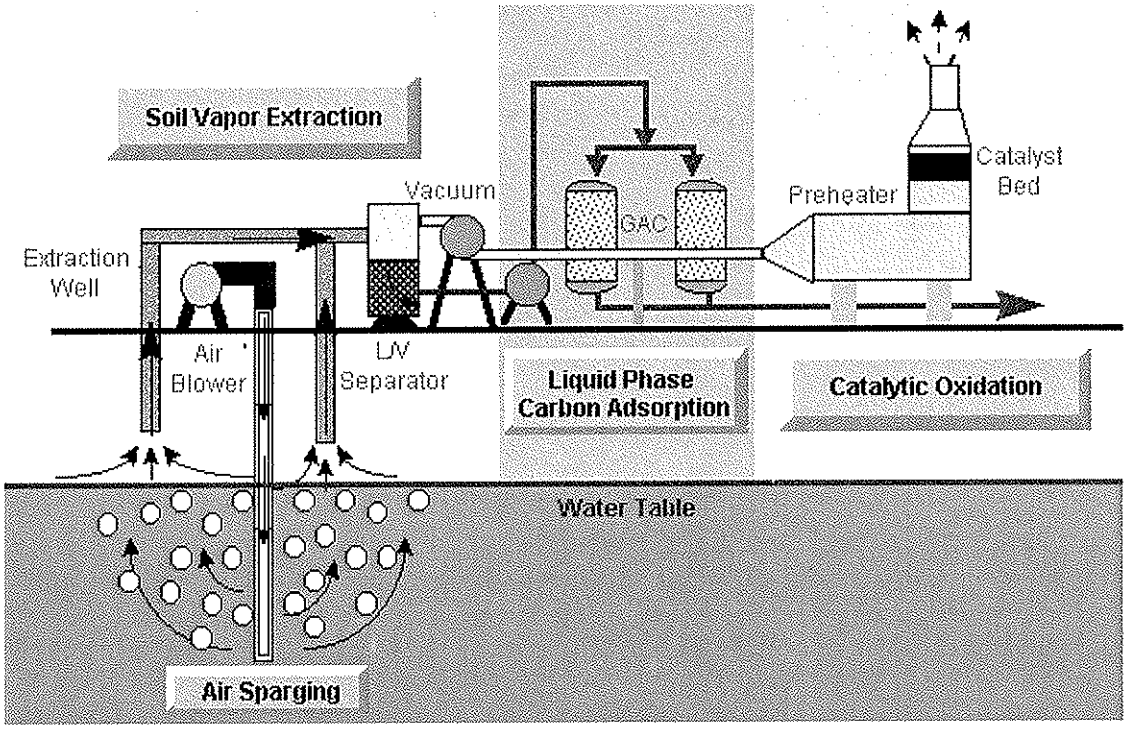
A treatment train is the combination of different treatment technologies. A system diagram of a common treatment train for nonhalogenated VOCs is illustrated below. A soil vapor extraction system is used to pull VOC vapor from the contaminated soil. An air sparging system delivers air below the water table to enhance bioremediation. After passing through a liquid/vapor separator, the VOC contaminated water and gas are pumped to a liquid phase granulated activated carbon (GAC) adsorption system. The GAC system removes VOCs in the water. The effluent is either discharged or pumped back as fluid recycling. Meanwhile, VOCs in the gas stream are completely destroyed through catalytic oxidation. Carbon dioxide and water vapor are discharged to the atmosphere as the final products of oxidation.

Click on the different color areas to see detail profiles of the technologies involved.



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2.4 HALOGENATED VOLATILE ORGANIC COMPOUNDS

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Sites where halogenated 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 2-2. Typical halogenated VOCs encountered at many sites include the following:

1,1,1,2-Tetrachloroethane	Bromoform	Glycerol trichlorohydrin
1,1,1-Trichloroethane	Bromomethane	Hexachlorobutadiene
1,1,2,2-Tetrachloroethane	Carbon tetrachloride	Hexachlorocyclopentadiene
1,1,2-Trichloroethane	Chlorodibromomethane	Hexachloroethane
1,1-Dichloroethane	Chloroethane	Methylene chloride
1,1-Dichloroethylene	Chloroform	Neoprene
1,2,2-Trifluoroethane (Freon 113)	Chloromethane	Pentachloroethane
1,2-Dichloroethane	Chloropropane	Perchloroethylene
1,2-Dichloropropane	Cis-1,2-dichloroethylene	Propylene dichloride
1,2-Trans-dichloroethylene	Cis-1,3-dichloropropene	Trichlorotrifluoroethane
1,3-cis-dichloro-1-propene	Dibromochloropropane	Monochlorobenzene
1,3-trans-dichloropropene	Dibromomethane	Tetrachloroethylene (Perchloroethylene) (PCE)
1-chloro-2-propene	Dichlorobromomethane	Trichloroethylene (TCE)
2-butylene dichloride	Dichloromethane	Vinyl chloride
Acetylene tetrachloride	Ethylene dibromide	Vinyl trichloride
Bromodichloromethane	Fluorotrichloromethane (Freon 11)	Vinylidene chloride

Click here, for further information on specific contaminants: Contaminant Specific Web Sites
Click here, for DOE's Preferred Alternatives Matrices (PAMs): PAMs

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2.4.1 Properties and Behavior of Halogenated VOCs

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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 VOCs have been 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 bioremediate than nonhalogenated compounds. In addition, the more halogenated the compound (i.e., the more halogens attached to it), the more resistant it is to 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 ground water 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 ground water 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 ground water aquifers. Light NAPLs (LNAPLs) will float on top of surface water and ground water. 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.

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2.4.2 Common Treatment Technologies for Halogenated VOCs in Soil, Sediment, Bedrock and Sludge

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Soil vapor extraction (SVE), thermal desorption, and incineration are the presumptive remedies for Superfund sites with halogenated 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 halogenated 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.

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2.4.3 Common Treatment Technologies for Halogenated VOCs in Ground Water, Surface Water and Leachate

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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 ground water. **Treatability studies** to characterize the biodegradability may be needed for any biodegradation technologies. Treatability studies are usually necessary to ensure that the contaminated ground water can be treated effectively at the design flow. A **subsurface geologic** characterization would be needed for any isolation or stabilization technologies. **Ground water 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 halogenated VOCs in ground water, surface water, and leachate are air stripping and carbon adsorption. These are both ex situ technologies requiring ground water 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 ground water 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 taken off-site for disposal. Carbon used for explosives- or metals-contaminated ground water must be removed and properly disposed of. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes.

Other fairly common technologies used in separating contaminants from ground water are distillation and membrane pervaporation.

Membrane pervaporation is a process that uses permeable membranes that preferentially adsorb volatile organic compounds (VOCs) from contaminated water. Contaminated water first passes through a heat exchanger, raising the water temperature. The heated water then enters the pervaporation module, containing membranes composed of a nonporous organophilic polymer, similar to silicone rubber, formed into capillary fibers. VOCs diffuse by vacuum from the membrane-water interface through the membrane wall. Treated water exits the pervaporation module, while the organic vapors travel from the module to a condenser where they return to the liquid phase. The condensed organic materials represent only a fraction of the initial wastewater volume and may be subsequently disposed of at a cost savings.

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2.4.4. Common Treatment Technologies for Halogenated VOCs in Air Emissions/ Off-Gases

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Three technologies that are most commonly used to treat halogenated 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. Oxidation of halogenated VOCs produces acid vapor. Off gas scrubbing may be needed to control the acid vapor.

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. Catalysts that resist damage from halogenated VOC combustion are available, but cost more than catalysts that are suitable for nonhalogenated VOC combustion.

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. Like catalytic oxidation, thermal oxidation of halogenated VOCs produces acid vapor. Off gas scrubbing may be needed to control the acid vapor.

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2.4.5 Common Treatment Train for Halogenated VOCs

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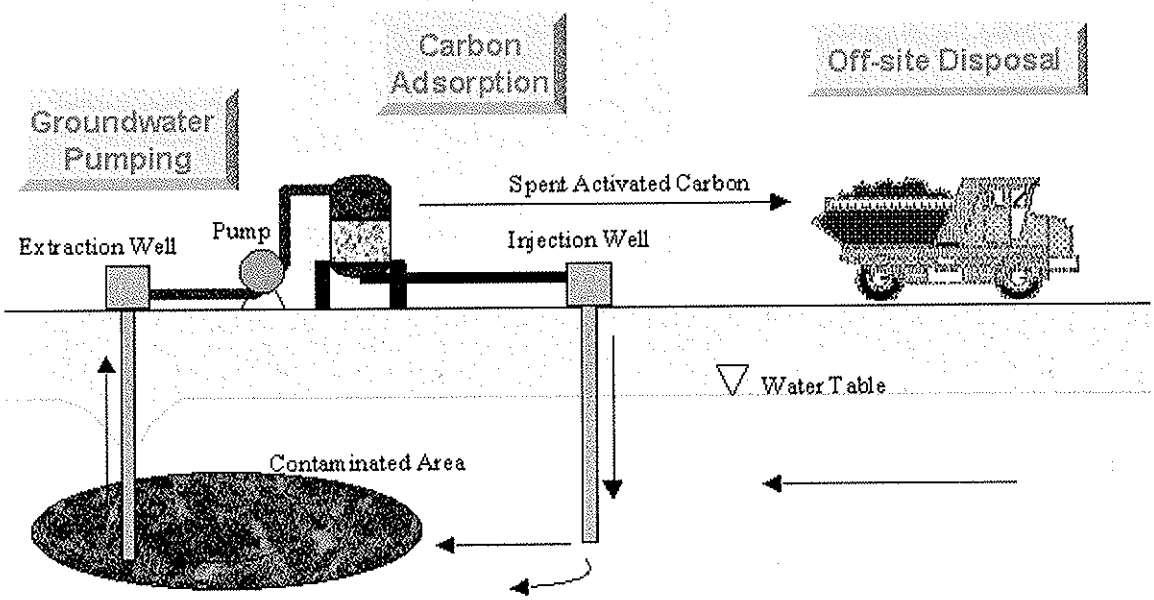
In general, no single technology can remediate an entire site. Several treatment technologies are usually combined at a single site to form what is known as a treatment train. A system diagram of a common treatment train for halogenated VOCs is illustrated below. A ground water pumping system is used to pull contaminated water from the subsurface. The VOC contaminated water is pumped to a liquid phase granulated activated carbon (GAC) adsorption system. The GAC system removes VOCs in the water and the effluent is either discharged or re-injected back into the subsurface. Additionally, exhausted GAC is taken off-site for either reactivation, regeneration, or disposal once the effluent (treated water) no longer meets the treatment objective. The exhausted GAC is replaced with new GAC. If GAC is to be discarded, it may have to be handled as a hazardous waste. In most cases, spent GAC can be regenerated, typically using steam to desorb and collect concentrated contaminants for further treatment.

Click on the different color areas to see detail profiles of the technologies involved.



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2.5 NONHALOGENATED SEMIVOLATILE ORGANIC COMPOUNDS (SVOCs)

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Sites where nonhalogenated 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 2-3. Typical nonhalogenated SVOCs (excluding fuels and explosives, which are presented in Subsection 2.7 and subsection 2.10) encountered at many sites include the following:

1,2-benzacenaphthene	Benzidine	Ethyl parathion
1,2-Diphenylhydrazine	Benzo(a)anthracene	Fluorene
1-aminonaphathalene	Benzo(a)pyrene	Indeno(1,2,3-cd)pyrene
2,3-phenylenepyrene	Benzo(b)fluoranthene	Isophorone
2,4,-Dinitrophenol	Benzo(k)fluoranthene	Malathion
2-aminonaphthalene	Benzoic Acid	Methylparathion
2-Methylnaphthalene	Benzyl alcohol	Naphthalene
2-Nitroaniline	Bis(2-ethylhexyl)phthalate	n-Nitrosodimethylamine
2-Nitrophenol	Butyl benzyl phthalate	n-Nitrosodi-n-propylamine
3-Nitroaniline	Chrysene	n-Nitrosodiphenylamine
4,6-Dinitro-2-methylphenol	Dibenzofuran	Parathion
4-Nitroaniline	Diethyl phthalate	Phenanthrene
4-Nitrophenol	Dimethyl phthalate	Phenyl naphthalene
Acenaphthene	Di-n-butyl phthalate	Pyrene
Acenaphthylene	Di-n-octyl phthalate	tetraphene
Allyldioxybenzene methylene ether	Diphenylenemethane	
Anthracene	Ethion	

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2.5.1 Properties and Behavior of Nonhalogenated SVOCs

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Typical nonhalogenated SVOCs are listed at the beginning of Subsection 2.5. Subsurface contamination by nonhalogenated 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 nonhalogenated SVOCs is much less than for nonhalogenated 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 ground water aquifers. LNAPLs will float on top of surface water and ground water. 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 nonhalogenated 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.

- **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 their categorization on the applicability of a substance or product to the type of pest control desired. 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.

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2.5.2 Common Treatment Technologies for Nonhalogenated SVOCs in Soil, Sediment, Bedrock and Sludge

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Common treatment technologies for nonhalogenated 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 ground water. 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.

In situ bioremediation of soil typically involves the percolation or injection of ground water or uncontaminated water containing dissolved oxygen and 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. Bioventing is also potentially applicable to some nonhalogenated SVOCs.

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.

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, retrieval, and off-site disposal 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.

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2.5.3 Common Treatment Technologies for Nonhalogenated SVOCs in Ground Water, Surface Water, and Leachate

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In addition to the general data requirements discussed in **Subsection 2.2.2**, it may be necessary to know other subsurface information to remediate nonhalogenated 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 ground water can be treated effectively at the design flow. A **subsurface geologic** characterization would be particularly useful to any isolation or stabilization technologies. **Ground water 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 nonhalogenated SVOCs in ground water and surface water include carbon adsorption and UV oxidation. In situ treatment technologies are not widely used. Ground water and surface water concentrations are usually not sufficiently high to support biological processes, however, biological process may be applicable to leachate.

Liquid phase carbon adsorption is a full-scale technology in which ground water 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 ground water 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.

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2.5.4 Common Treatment Train for Nonhalogenated SVOCs

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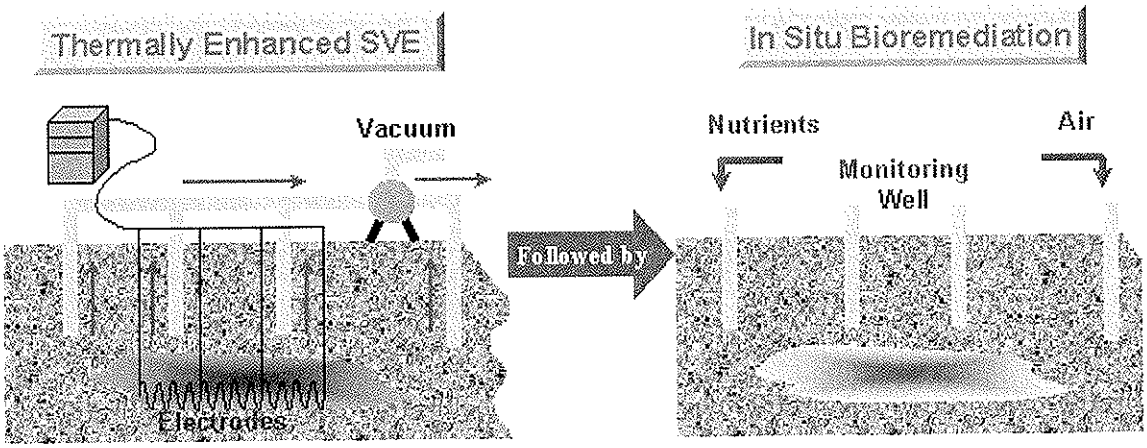
A treatment train is the combination of different treatment technologies. A system diagram of a common treatment train for nonhalogenated SVOCs is illustrated below. A thermally enhanced soil vapor extraction system is used to pull SVOC vapor from the contaminated soil. Electrodes are installed in the contamination zone to enhance the desorption of SVOCs from the contaminated soil. The traditional soil vapor extraction system then pulls out the SVOC contaminated soil gas. After initial thermally enhanced soil vapor extraction, in situ bioremediation is used to carry out the second stage cleanup because it is more cost effective. Air and necessary nutrients are pumped into the contamination zone to enhance the intrinsic biodegradation.

Click on the different color areas to see detail profiles of the technologies involved.



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2.6 HALOGENATED SEMIVOLATILE ORGANIC COMPOUNDS (SVOCs)

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Sites where halogenated 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 2-4. Typical halogenated SVOCs, excluding fuels and explosives, which are presented in subsection 2.7 and subsection 2.10, encountered at many sites include the following:

1,2,4-Trichlorobenzene	4-Chloroaniline	Hexachlorobenzene
1,2-Bis(2-chloroethoxy) ethane	4-Chlorophenyl phenylether	Hexachlorobutadiene
1,2-Dichlorobenzene	Bis(2-chloroethoxy) ether	Hexachlorocyclopentadiene
1,3-Dichlorobenzene	Bis(2-chloroethoxy) methane	o-dichlorobenzene
1,4-Dichlorobenzene	Bis(2-chloroethoxy) phthalate	p-Chloro-m-cresol
2,4,5-Trichlorophenol	Bis(2-chloroethyl) ether	p-dichlorobenzene
2,4,6-Trichlorophenol	Bis(2-chloroisopropyl) ether	Pentachlorobenzene
2,4-Dichlorophenol	Chlordane	Pentachlorophenol (PCP)
2-Chloronaphthalene	Chlorobenzene	Polychlorinated biphenyls (PCBs)
2-Chlorophenol	Chlorobenzilate	Quintozene
3,3-Dichlorobenzidine	Chlorphenothane	Tetrachlorophenol
4-Bromophenyl phenyl ether	Hexachlorobenzene	Unsym-trichlorobenzene

- Pesticides:

Aldrin	4,4´-DDT	Ethyl parathion
BHC-alpha	Dieldrin	Heptachlor
BHC-beta	Endosulfan I	Heptachlor epoxide
BHC-delta	Endosulfan II	Malathion
BHC-gamma	Endosulfan sulfate	Methylparathion
Chlordane	Endrin	Parathion
4,4´-DDD	Endrin aldehyde	Toxaphene
4,4´-DDE	Ethion	

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2.6.1 Halogenated Properties and Behavior of SVOCs

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An important consideration when evaluating a remedy is whether the compound is halogenated or nonhalogenated. A halogenated compound is one onto which a halogen ion (e.g., fluorine, chlorine, bromine, or iodine) has been attached. Typical halogenated SVOCs are listed at the beginning of Subsection 2.6. 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 halogenated 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 halogenated SVOCs is much less than for halogenated 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 ground water aquifers. LNAPLs will float on top of surface water and ground water. 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 halogenated SVOC contaminants and contaminant groups are discussed below:

- **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 ground water 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.

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2.6.2 Common Treatment Technologies for Halogenated SVOCs in Soil, Sediment, Bedrock and Sludge

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

All types of biodegradation, in situ and 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 . 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 ground water 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.

Dehalogenation adds reagents to soils contaminated with halogenated SVOCs. The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.

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.

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

For incineration of halogenated SVOCs, off-gas treatment is needed to neutralize the acidic gas as the products of oxidation.

Excavation, retrieval, and off-site disposal 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.

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2.6.3 Common Treatment Technologies for Halogenated SVOCs in Ground Water, Surface Water, and Leachate

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In addition to the general data requirements discussed in **Subsection 2.2.2**, it may be necessary to know other subsurface information to remediate halogenated 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 ground water can be treated effectively at the design flow. A **subsurface geologic** characterization would be particularly useful to any isolation or stabilization technologies. **Ground water 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 halogenated SVOCs in ground water and surface water include carbon adsorption and UV oxidation. In situ treatment technologies are not widely used. Ground water and surface water concentrations are usually not sufficiently high to support biological processes, however, biological process may be applicable to leachate.

Liquid phase carbon adsorption is a full-scale technology in which ground water 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 ground water 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.

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2.6.4 Common Treatment Train for Halogenated SVOCs

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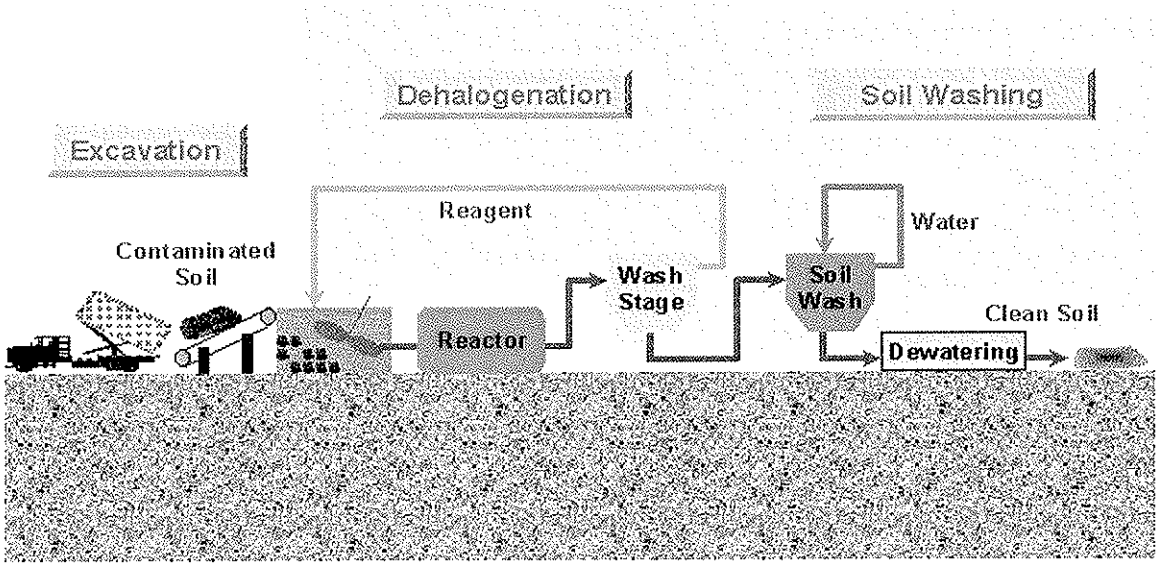
A treatment train is the combination of different treatment technologies. A system diagram of a common treatment train for halogenated SVOCs is illustrated below. Contaminated soil is excavated and transported to the treatment facility. A dehalogenation process is used to treat the contaminated soil first. In this process, soil is mixed with chemical reagents in a mixer and then passed through a reactor in which reactions between SVOCs and reagents take place. After dehalogenation, excess chemical reagents are separated from soil and recycled back to the mixer. Treated soil is finally cleaned by water in a soil washing process to remove contaminant residuals. Clean soil after dewatering is then ready for disposal.

Click on the different color areas to see detail profiles of the technologies involved.



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2.7 FUELS

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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 2-5. Typical fuel contaminants encountered at many sites include the following:

1,2,3,4-Tetramethylbenzene	2-Methylheptane	Benzo(k)fluoranthene	n-Decane
1,2,4,5-Tetramethylbenzene	2-Methylnaphthalene	Chrysene	n-Dodecane
1,2,4-Trimethyl- 5-ethylbenzene	2-Methylpentane	Cis-2-butene	n-Heptane
1,2,4-Trimethylbenzene	2-Methylphenol	Creosols	n-Hexane
1,3,5-Trimethylbenzene	3,3,5-Trimethylheptane	Cyclohexane	n-Hexylbenzene
1-Pentene	3,3-Dimethyl-1-butene	Cyclopentane	n-Nonane
2,2,4-Trimethylheptane	3-Ethylpentane	Dibenzo(a,h) anthracene	n-Octane
2,2,4-Trimethylpentane	3-Methyl-1,2-butadiene	Dimethylethylbenzene	n-Pentane
2,2-Dimethylheptane	3-Methyl-1-butene	Ethylbenzene	n-Propylbenzene
2,2-Dimethylhexane	3-Methyl-1-pentene	Fluoranthene	n-Undecane
2,2-Dimethylpentane	3-Methylheptane	Fluorene	o-Xylene
2,3,4-Trimethylheptane	3-Methylhexane	Ideno(1,2,3-c,d) pyrene	Phenanthrene
2,3,4-Trimethylhexane	3-Methylpentane	Isobutane	Phenol
2,3,4-Trimethylpentane	4-Methylphenol	Isopentane	Propane
2,3-Dimethylbutane	Acenaphthene	Methylcyclohexane	p-Xylene
2,3-Dimethylpentane	Anthracene	Methylcyclopentane	Pyrene
2,4,4-Trimethylhexane	Benz(a)anthracene	Methylnaphthalene	Pyridine
2,4-Dimethylphenol	Benzene	Methylpropylbenzene	Toluene
2-Methyl-1,3-butadiene	Benzo(a)pyrene	m-Xylene	Trans-2-butene
2-Methyl-2-butene	Benzo(b)fluoranthene	Naphthalene	Trans-2-pentene
2-Methyl-butene	Benzo(g,h,i)perylene	n-Butane	Vinylbenzene

Click here, for further information on specific contaminants: Contaminant Specific Web Sites
Click here, for DOE's Preferred Alternatives Matrices (PAMs): PAMs

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2.7.1 Properties and Behavior of Fuels

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Fuel contaminants are generally nonhalogenated. Information presented for nonhalogenated VOCs (Subsection 2.3.1) and nonhalogenated SVOCs (Subsection 2.5.1) may also be appropriate for many of the fuel contaminants presented in this subsection.

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 ground water 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 ground water 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 ground water transport. Vapor-phase transport can be followed by subsequent dissolution in ground water. 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 ground water 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.

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2.7.2 Common Treatment Technologies for Fuels in Soil, Sediment, Bedrock and Sludge

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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, bioslurping, biopiles (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 ground water. 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.

In situ bioremediation of soil typically involves the percolation or injection of ground water or uncontaminated water containing dissolved oxygen and 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. Bioventing is a presumptive remedy for fuels. Bioventing is an in situ technique that uses air injection to aerate the soil and enhance biodegradation. The AFCEE Bioventing Initiative currently encompasses more than 145 fuel sites at 56 military installations, including one Marine, three Army, and one Coast Guard facility. Approximately 50% of the current systems are full scale. As of September 1995, approximately 125 are installed and operating. The remainder is 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.

Ground water extraction pumps may be used to reduce ground water 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. Ground water 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.

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2.7.3 Common Treatment Technologies for Fuels in Ground Water, Surface Water, and Leachate

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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 ground water. Treatability testing to characterize contaminant biodegradability and **nutrient content** may be needed for any biodegradation technology. A **subsurface geologic** characterization would be particularly important to characterize the migration of NAPLs. **Recovery tests** are usually necessary to design a product/ground water pumping scheme that will ensure that the nonaqueous fuel layer can be recovered and that contaminated ground water can be treated effectively at the design flow. **Ground water 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 ground water include air stripping, carbon adsorption, dual phase extraction, fluid/vapor extraction, and bioslurping. These are all ex situ treatment technologies requiring ground water extraction.

Air stripping involves the mass transfer of volatile contaminants from water to air. For ground water 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 ground water 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 taken off-site for disposal. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes.

For dual phase extraction, 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). Dual phase extraction is a full-scale technology.

Bioslurping is the adaptation and application of vacuum-enhanced dewatering technologies to remediate hydrocarbon-contaminated sites. Bioslurping combines vacuum-assisted free-product recovery with bioventing to simultaneously recover free product and bioremediate vadose zone soils. Bioslurping can improve free-product recovery efficiency

without extracting large quantities of ground water. Bioventing of vadose zone soils is achieved by drawing air through the soil via the recovery well. The system is designed to minimize environmental discharge of ground water and soil gas. When free-product removal activities are completed, the bioslurping system is easily converted to a conventional bioventing system to complete the remediation.

Air sparging is an in situ technology in which air is injected through a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper that removes contaminants by volatilization. This injected air helps to flush (bubble) the contaminants up into the unsaturated zone where a vapor extraction system is usually 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 ground water and soil and strip more ground water by sparging.

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2.7.4 Common Treatment Train for Fuels

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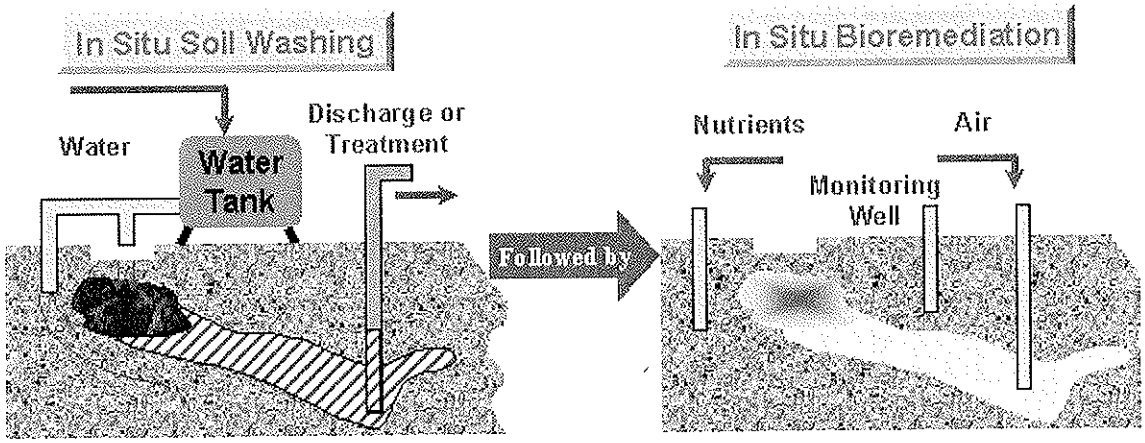
A treatment train is the combination of different treatment technologies. A system diagram of a common treatment train for fuels is illustrated below. The fuel contaminated soil is first treated using a soil washing process. Water is injected at the up stream side of the contaminated site. Surfactant or other additives may be added to enhance the soil washing effect. Contaminated water is pulled out through extraction wells installed at the down stream side for further treatment. An in situ bioremediation process is used, following the initial soil washing, to complete the remediation. Nutrients and air may be pumped in to the site if necessary to enhance intrinsic bioremediation.

Click on the different color areas to see detail profiles of the technologies involved.



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2.8 INORGANICS

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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 2-6. Typical inorganic contaminants encountered at many sites include the following:

- Metals

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

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

- Other inorganic contaminants

Asbestos
Fluorine
Cyanide

Click here, for further information on specific contaminants: Contaminant Specific Web Sites
Click here, for DOE's Preferred Alternatives Matrices (PAMs): PAMs

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2.8.1 Properties and Behavior of Inorganics

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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 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 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. The properties and behavior of specific inorganics, mainly metals, are discussed below. The properties and behavior of radionuclides are discussed separately in section 2.9.1.

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

  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.

- **Barium:** Barium (Ba) metal does not occur in nature. The most common ores are the sulfate (barite) and the carbonate (witherite). The largest end use of barium metal is as a "getter" to remove the last traces of gases from vacuum and television picture tubes. The most important compounds are the peroxide, chloride, sulfate, carbonate, nitrate, and chlorate. Barium peroxide is used as a bleach, in dyes, fireworks and tracer-bullets, and in igniter and welding materials. Barium sulfate is used as permanent white in paint, in X-ray diagnostic work, in glassmaking, and as a pigment in Lithopone (with zinc sulfide). Barite is extensively used as a wetting agent in oil-well drilling fluids, and also in making rubber. The carbonate is used as a rat poison,

while the nitrate and chlorate give colors in pyrotechny. All barium compounds that are water or acid soluble are poisonous.

Barium is released to water and soil in the discharge and disposal of drilling wastes, from the smelting of copper, and the manufacture of motor vehicle parts and accessories. In water, the more toxic barium salts are likely to precipitate out as the less toxic insoluble sulfate or carbonate. Barium is not very mobile in most soil systems. Adsorption of barium was measured in a sandy soil and a sandy loam soil at levels closely corresponding to those expected for field conditions. In general, sludge solutions appeared to increase the mobility of elements in a soil. This is due to a combination of complexation by dissolved organic compounds, high background concentration and high ionic strengths of the soil solution.

- **Cadmium:** Cadmium (Cd) most often occurs in small quantities associated with zinc ores, but also with copper and lead ores. It is used primarily for metal plating and coating operations, including transportation equipment, machinery and baking enamels, photography, and television phosphors. It is also used in nickel-cadmium and solar batteries, in pigments, as a stabilizer in plastics and synthetic products, as alloys and the other purposes. It also is used in many types of solder (e.g., silver solder).

  Cadmium oxide and sulfide are relatively insoluble while the chloride and sulfate salts are soluble. The adsorption of cadmium onto soils and silicon or aluminum oxides is strongly pH-dependent, increasing as conditions become more alkaline. When the pH is below 6-7, cadmium is desorbed from these materials. Cadmium has considerably less affinity for the absorbents tested than do copper, zinc, and lead and might be expected to be more mobile in the environment than these materials. Studies have indicated that cadmium concentrations in bed sediments are generally at least an order of magnitude higher than in the overlying water.

  Addition of anions, such as humate or tartrate, to dissolved cadmium cause an increase in adsorption. The mode by which cadmium is sorbed to the sediments is important in determining its disposition towards remobilization. Cadmium found in association with carbonate minerals, precipitated as stale solid compounds, or co-precipitated with hydrous iron oxides would be less likely to be mobilized by resuspension of sediments or biological activity. Cadmium absorbed to mineral surfaces (e.g., clay) or organic materials would be more easily bioaccumulated or released in the dissolved state when sediments are disturbed, such as during flooding.

- **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. This association decreases with increasing soil pH. Iron and aluminum oxide surfaces adsorb the chromate ion at an acidic or neutral pH. Industrial applications, except leather tanning, use Cr(VI) but the reaction rate limits the conversion from Cr(VI) to Cr(III) under typical environmental conditions.

  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. Copper has high toxicity to aquatic organisms.

- **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, ground water (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 ground water.

- **Mercury:** Mercury is extremely toxic and very mobile in the environment. 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.

- **Selenium:** Selenium (Se). Selenium occurs in nature usually in the sulfide ores of the heavy metals and constitutes about 0.09 ppm of the earth's crust. It is the most strongly enriched element in coal, being present as an organoselenium compound, a chelated species, or as an adsorbed element. Selenium is used extensively in the manufacture and production of glass, pigments, rubber, metal alloys, textiles, petroleum, medical therapeutic agents, and photographic emulsions. Selenium dioxide is the most widely used selenium compound in industry. It is used as an oxidizing agent in drug and other chemical manufacture; a catalyst in organic syntheses; and an antioxidant in lubricating oils. (Note: Selenium is not a true metal;

however, it is included here as it is one of the eight RCRA metals.)

The toxicity of selenium depends on whether it is in the biologically active oxidized form. In alkaline soils and oxidizing conditions, selenium may be oxidized sufficiently to maintain the availability of its biologically active form, and cause plant uptake of the metal to be increased. In acidic or neutral soils, it tends to remain relatively insoluble and the amount of biologically available selenium should steadily decrease. Selenium volatilizes from soils when converted to volatile selenium compounds (e.g., dimethyl selenide) by microorganisms.

- **Silver:** Silver (Ag) occurs naturally and in ores such as argentite (Ag2S) and horn silver (AgCl). Lead, lead-zinc, copper, gold, and copper-nickel ores are the principal source. It is used for jewelry, silverware, etc., and in photography, dental alloys, solder and brazing alloys, electrical contacts, high capacity silver-zinc and silver-cadmium batteries, mirrors, and coinage. Silver nitrate, the most important silver compound, is used extensively in photography. Silver iodide is used in seeding clouds to produce rain. Silver chloride has interesting optical properties as it can be made transparent; it also is a cement for glass.

  While silver itself is not considered to be toxic, most of its salts are poisonous due to the anions present. Silver compounds can be absorbed in the circulatory system and reduced silver deposited in the various tissues of the body. Silver is regulated under RCRA.

- **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.

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2.8.2 Common Treatment Technologies for Inorganics in Soil, Sediment, Bedrock and Sludge

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The most commonly used treatment technologies for inorganics in soil, sediment, and sludge include **solidification/stabilization** (S/S), excavation and off-site disposal, and acid extraction. 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 chemical binders, such as cement, silicates, or pozzolans, 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 off-site disposal of contaminated soil (with or without solidification/stabilization pretreatment) 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.

Acid extraction uses an acid, such as hydrochloric acid, to extract heavy metal contaminants from soils. In this process, soils are first screened to remove coarse solids. Hydrochloric acid is then introduced into the soil in the extraction unit. The residence time in the unit varies depending on the soil type, contaminants, and contaminant concentrations, but generally ranges between 10 and 40 minutes. The soil-extractant mixture is continuously pumped out of the mixing tank, and the soil and extractant are separated using hydrocyclones.

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2.8.3 Common Treatment Technologies for Inorganics in Ground Water, Surface Water, and Leachate

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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 ground water, surface water, and leachate. **Treatability studies** are usually necessary to ensure that the contaminated ground water 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. **Ground water 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 ground water 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 the removal of metals from ground water. This technology pumps ground water 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 the 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 ground water 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. Other types of ion exchange materials include clays, zeolites, and peat derivatives. 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 to10% 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.

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2.8.4 Common Treatment Train for Inorganics

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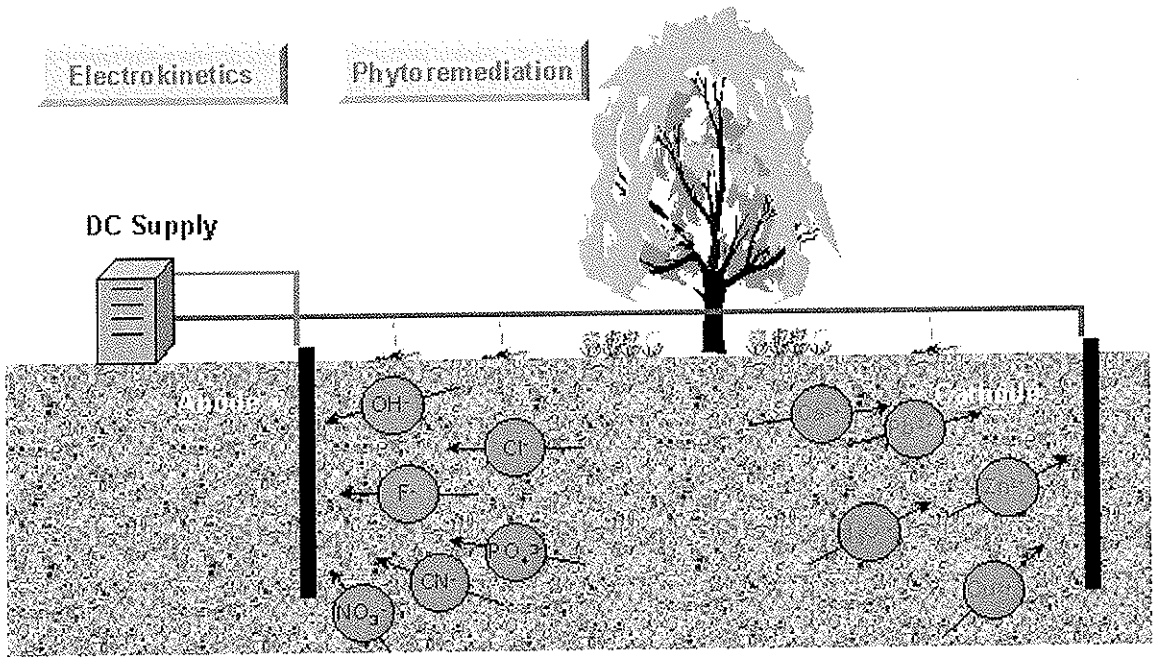
A treatment train is the combination of different treatment technologies. A system diagram of a common treatment train for inorganics is illustrated below. Metal contaminated soil is treated using the combination of electrokinetics and phytoremediation. Electrokinetics is used to remove metals from deep soil and ground water. A low density direct current is applied to mobilize charged species, causing ions and water to move toward the electrodes. Metal ions move toward the cathode, and anions move toward anode. Removal of metal contaminants at the electrode may be accomplished by electroplating at the electrode; precipitation or co-precipitation at the electrode; pumping of water near the electrode. Metals in the topsoil can be removed by phytoremediation. Metal ions are picked up by plant roots and accumulated into plant shoots and leaves.

Click on the different color areas to see detail profiles of the technologies involved.



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2.9 RADIONUCLIDES

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Sites where radionuclide contaminants may be found are mainly radioactive and mixed waste disposal areas. Potentially applicable remediation technologies are presented in Table 2-7. Typical radionuclide contaminants encountered include the following:

Americium-241	Iodine-129,-131	Ruthenium-103,106
Barium-140	Krypton-85	Silver-110m
Carbon-14	Molybdemum-99	Strontium-89,-90
Cerium-144	Neptunium-237	Technetium-99
Cesium-134, -137	Plutonium-238, -239,-241	Tellurium-132
Cobalt-60	Polonium-210	Thorium-228, -230, -232
Curium-242,-244	Radium-224, -226	Tritium
Europium-152, -154, -155	Radon-222	Uranium-234, -235, -238

Click here, for further information on specific contaminants: Contaminant Specific Web Sites
Click here, for DOE's Preferred Alternatives Matrices (PAMs): PAMs

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2.9.1 Properties and Behavior of Radionuclides

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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 2.9 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, will be greater than that of thorium-230, which is much less soluble and poses a significant challenge for separation technologies.

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 to workers (internal and external) and the technologies themselves. 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 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 with half-lives greater than 20 years per gram of waste). 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; in addition, there is no

storage currently available for mixed TRU. For example, commercial LLW disposal capacity is no longer 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.

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2.9.2 Common Treatment Technologies for Radionuclides in Soil, Sediment, Bedrock and Sludge

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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. The most commonly used treatment technology for radionuclides in soil, sediment, and sludge is solidification/stabilization (S/S). This treatment technology is described briefly below.

Solidification processes produce monolithic blocks of waste with high structural integrity. The radionuclides 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 chemical binders, such as cement, silicates, or pozzolans, which limit the solubility or mobility of waste constituents even though the physical handling characteristics of the waste may not be changed or improved. Solidification/stabilization of radionuclides can be conducted either in situ or ex situ. In situ S/S techniques are now considered innovative and are discussed in Section 4.

There are many innovations in the stabilization and solidification technology. Most of the innovations are modifications of proven processes and are directed to encapsulation or immobilizing the harmful constituents and involve processing of the waste or radionuclides. Some distinct innovative processes include: radioactive waste solidification and vitrification/molten glass.

In radioactive waste solidification (Grouting/Other) treatment, solidification additives are used to form a uniform and stable matrix to encapsulate radioactive waste materials. Assemblies include pumps for liquids or slurries, conveyors for sludges or solids, storage silos, weigh feeders, piping, mixers and disposal or storage.

Vitrification, or molten glass, processes are solidification methods that employ heat up to 1,200° C to melt and convert waste materials into glass or other glass and crystalline products. The high temperatures destroy any organic constituents with very few byproducts. Materials, such as heavy metals and radionuclides, are actually incorporated into the glass structure which is, generally, a relatively strong, durable material that is resistant to leaching. In addition to solids, the waste materials can be liquids, wet or dry sludges, or combustible materials. Borosilicate and soda-lime are the principal glass formers and provide the basic matrix of the vitrified product.

Excavation, retrieval, and off-site disposal of contaminated soil (with or without stabilization) to a landfill have been performed previously at many sites. Landfilling of radionuclides 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.

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2.9.3 Common Treatment Technologies for Radionuclides in Ground Water, Surface Water, and Leachate

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In addition to the general data requirements discussed in **Subsection 2.2.2**, it may be necessary to know other subsurface information to remediate radionuclides in ground water, surface water, and leachate. **Treatability studies** are usually necessary to ensure that the contaminated ground water 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. **Ground water 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 treatment technologies for radionuclides in ground water and are discussed in the following paragraphs.

The combination of precipitation/flocculation and sedimentation is a well-established technology for radionuclides removal from ground water. This technology pumps ground water through extraction wells and then treats it to precipitate radionuclides and heavy metals. Typical removal of radionuclides 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.

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 ground water 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 to10% wastestream that must be treated separately.

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2.9.4 Common Treatment Train for Radionuclides

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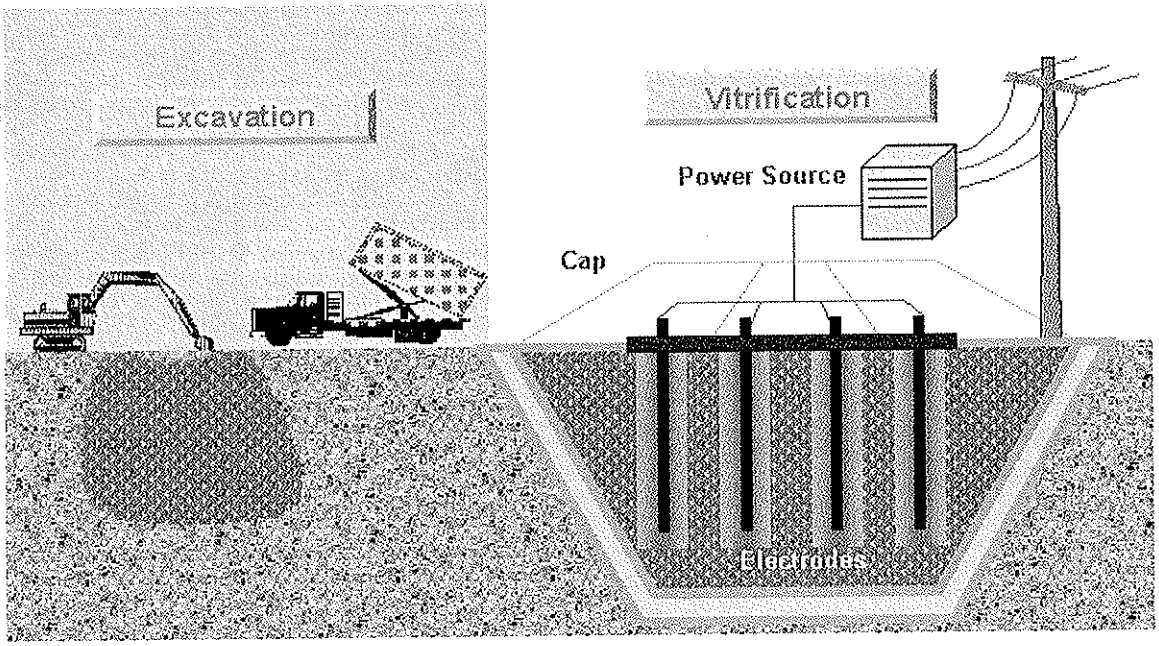
A treatment train is the combination of different treatment technologies. A system diagram of a common treatment train for radionuclides is illustrated below. Radionuclide contaminated soil is first excavated from the contamination soil and transported to a vitrification site. During vitrification, the contaminated soil is molten at extremely high temperatures. Radionuclides are incorporated into the molten glass structure, which is a strong durable material resistant to leaching.

Click on the different color areas to see detail profiles of the technologies involved.



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2.10 EXPLOSIVES

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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 2-8. Typical explosive contaminants encountered at many sites include the following:

• TNT (2,4,6-Trinitrotoluene)	• Picrates
• RDX (Cyclo-1,3,5-trimethylene-2,4,6-trinitramine)	• TNB (Trinitrobenzenes)
• Tetryl (N-Methyl-N,2,4,6-tetranitrobenzeneamine)	• DNB (Dintrobenzenes)
• 2,4-DNT (2,4-Dinitrotoluene)	• Nitroglycerine
• 2,6-DNT (2,6-Dinitrotoluene)	• Nitrocellulose
• HMX (1,3,5,7-Tetranitro-1,3,5,7-tetraazocyclooctane)	• AP (Ammonium perchlorate)
• Nitroaromatics	• Nitroglycerine

Click here, for further information on specific contaminants: Contaminant Specific Web Sites
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2.10.1 Properties and Behavior of Explosives

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Information presented for SVOCs (Subsection 2.5.1 and 2.6.1) 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 ground water 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

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.

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2.10.2 Common Treatment Technologies for Explosives in Soil, Sediment, Bedrock and Sludge

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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 ground water.

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 in Sections 2.10.2.1 to 2.10.2.3.

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2.10.2.1 Biological Treatment Technologies for Explosives

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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 six biological treatments for explosives-contaminated soils: aqueous-phase bioreactor treatment; composting, land farming, phytoremediation, 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 ° or 131 to 140 °) 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.

Landfarming: Landfarming 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. However, the study achieved a 30 to 40% contaminant degradation.

Phytoremediation: The U.S. Army Environmental Center (USAEC) is developing technologies to effectively clean up contaminated soil with residues of explosives like TNT, RDX, HMX, and DNT. One potential treatment alternative is phytoremediation using constructed wetlands. Phytoremediation is a process which uses plants to degrade, not uptake, explosives. Once this process is proven in constructed wetlands, it could be applied in natural wetlands to remediate explosives-contaminated ground water. Constructed wetlands have already proven to be effective for treating acid mine drainage and municipal waste waters. Wetlands phytoremediation is a technology that is relatively self-sustaining and cost-effective to maintain. In addition, this technology, unlike GAC, does not produce secondary waste streams.

In bench-scale testing, the EPA National Exposure Research Laboratory in Athens, GA, has identified a plant nitroreductase enzyme shown to degrade TNT, RDX, and HMX in concert with other plant enzymes. An immunoassay test has been developed that identifies nitroreductase activity in a wide variety of aquatic and terrestrial plants. This opens a door to a variety of potential applications for cleanup using plants in wetlands.

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.

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2.10.2.2 Thermal Treatment Technologies for Explosives

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Hot gas decontamination: Hot gas decontamination is a technology still in the pilot-scale of development that can 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.

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 °C to 649 °C (800 °F to 1,200 °F), and the temperature of soils ranges from 316 °C to 427 °C (600 °F 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 °C to 200 °C (3,600 °F 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 °C to 820 °C (1,200 °F 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, which 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.

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2.10.2.3 Other Treatment Technologies for Explosives

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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.

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2.10.3 Common Treatment Technologies for Explosives in Ground Water, Surface Water, and Leachate

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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 ground water. Therefore, ground water 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 ground water should be considered before transferring technologies from one application to another.

Granular-activated carbon (GAC) adsorption is commonly used for explosives-contaminated ground water 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 ground water 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 ground water contaminated from disposal of these process waters.

USAE-WES is evaluating a perozone system for explosives-contaminated ground water 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.

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2.10.4 Common Treatment Train for Explosives

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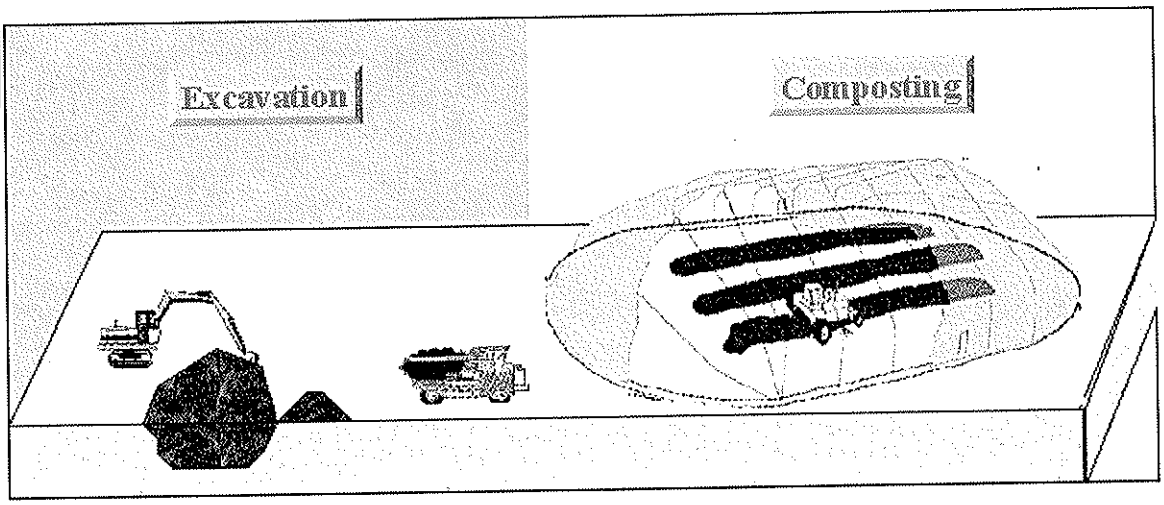
In general, no single technology can remediate an entire site. Several treatment technologies are usually combined at a single site to form what is known as a treatment train. A system diagram of a common treatment train for explosives is illustrated below. Explosive contaminated soil is first excavated from the site and transported to a windrow composting site. During windrow composting, contaminated soil is placed in a pile under a protective shelter and mixed with readily degradable carbon sources by a mechanical mixing vehicle.

Click on the different color areas to see detail profiles of the technologies involved.



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Section 3 Treatment Perspectives

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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 chemical 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 ground water 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.

These concepts about site remediation strategies and representative technologies associated with them are summarized in Figure1: Classification of Remedial Technologies by Function. 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 ground water pumping and air stripping to simultaneously remove contaminants from both ground water 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 14 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).
  - Containment.
  - Other treatment processes.
- Ground water, 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).
  - Containment.
- Air emissions/off-gas treatment.

These 14 treatment groups correspond to the following 14 subsections (3.1 through 3.14). The discussion of the broad application of each treatment group (e.g., in situ biological treatment for soil, sediment, bedrock 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 *Treatment Technologies for Site Cleanup: Annual Status Report Tenth Edition (February 2001)*, 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).
- Developmental Status (full scale vs. pilot scale).
- Typical Treatment Train.
- Residuals Produced.
- O&M or Capital Intensive.
- Availability.
- Contaminants Treated.
- System Reliability/Maintainability.
- Cleanup Time.
- Overall Cost.

Additionally, a brief description of each treatment technology is presented at the beginning of each process description.

TABLE 3-1a. DEFINITION OF LEGENDS USED IN THE TREATMENT TECHNOLOGIES SCREENING MATRIX

Factors	Definitions			
Development Status Scale status of an available technology.	**F** Full scale: technology has been used in real site remediation.		**P** Pilot Scale: studies conducted in the field or the laboratory to fine-tune the design of the technology.	
Treatment Train Is the technology only effective as part of the treatment train?	**Y** Technology must be used with the combination of other technologies as a treatment train.		**N** Technology can be used as a stand alone one.	
Residuals Produced Residuals need to be treated.	**S** Solid	**L** Liquid	**V** Vapor	**N** None

O&M or Capital Intensive Main cost intensive parts.	**O&M** Operation and Maintenance Intensive	**Cap** Capital Intensive	**B** Both O&M and Capital Intensive	**N** Neither O&M or Capital Intensive

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

Factors and Definitions	Worse △	Average ○	Better ▩	Other ◈
Availability Number of vendors that can design, construct, and maintain the technology.	Fewer than 2 vendors	2-4 vendors	More than 4 vendors	Data Not Available
Contaminants Treated Contaminants are classified into the following eight groups: - Nonhalogenated VOCs; - Halogenated VOCs; - Nonhalogenated SVOCs; - Halogenated SVOCs; - Fuels; - Inorganics; - Radionuclides; - Explosives.	No Demonstrated Effectiveness at Pilot or Full Scale	Limited Effectiveness Demonstrated at Pilot or Full Scale	Effectiveness Demonstrated at Pilot or Full Scale	Level of Effectiveness highly dependent upon specific contaminant and its application/design
System Reliability /Maintainability The expected range of demonstrated reliability and maintenance relative to other effective technologies	Low reliability and high maintenance	Average reliability and average maintenance	High reliability and low maintenance	Not applicable
Cleanup Time provided that this technology is effective for this specific contaminant. 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 ground water.	More than 3 years for in situ soil	1-3 years	Less than 1 year	Contaminant specific
	More than 1 year for ex situ soil	0.5-1 year	Less than 0.5 year	Contaminant specific
	More than 10 years for water	3-10 years	Less than 3 years	Contaminant specific
Overall Cost Design, construction, and operations and maintenance (O&M) costs of the core process that defines each technology, exclusive of mobilization,	More than $330/metric ton ($300/ton) for soils	$110-$330 /metric ton ($100-$300 /ton)	Less than $110/metric ton ($100/ton)	Contaminant specific
	More than	$0.79-	Less than	Contaminant

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 ground water technologies, it is assumed that pumping costs average $0.07/1,000 liters ($0.25/1,000 gallons).	$2.64/1,000 liters ($10/1,000 gal.) for ground water	$2.64 /1,000 liters ($3.00-$10.00/ 1,000 gallons)	$0.79/1,000 liters ($3.00/1,000 gallons)	specific
	More than $11.33/kg ($25/lb) for air emissions and off-gases	$3.17-$11.33 /kg ($7-$25/lb)	Less than $3.17/kg ($7/lb)	Contaminant specific

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

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3.1 In Situ Biological Treatment for Soil, Sediment, Bedrock and Sludge

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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 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). For in situ applications, these by-products may be mobilized to ground water or contacted directly if no control techniques are used. This type of treatment scheme requires soil, aquifer, and contaminant characterization, and may require extracted ground water treatment. Ground water 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 ground water 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 and their concentrations, oxygen supply, moisture, temperature, pH, nutrient supply, bioaugmentation, and cometabolism. 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. 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, or 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 bioventing, enhanced biodegradation, and phytoremediation. These technologies are discussed in Section 4 . Completed in situ biological treatment projects for soil, sediment, bedrock, and sludge are shown in Table 3-4 and additional information on completed demonstration projects are shown on the FRTR Web Site.

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3.3 In Situ Thermal Treatment for Soil, Sediment, Bedrock and Sludge

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The main advantage of in situ thermal 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.

An available in situ thermal treatment technology is thermally enhanced SVE. This technology is discussed in Section 4. Completed in situ thermal treatment projects for soil, sediment, bedrock and sludge are shown in Table 3-6 and additional information on completed demonstration projects are shown on the FRTR Web Site.

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3.4 Ex Situ Biological Treatment for Soil, Sediment, Bedrock and Sludge

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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 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 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 it is 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 ground water contaminated by petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Bioremediation is not yet commonly 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 biopiles, composting, landfarming, and slurry phase biological treatment. These technologies are discussed in Section 4. Completed ex situ biological treatment projects for soil, sediment, bedrock and sludge are shown inTable 3-7 and additional information on completed demonstration projects are shown on the FRTR Web Site.

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3.5 Ex Situ Physical/Chemical Treatment for Soil, Sediment, Bedrock and Sludge

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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/worker exposure conditions.

Physical/chemical treatment uses the physical properties of the contaminants or the contaminated medium to destroy (i.e., chemically convert), separate, or immobilize the contamination. Chemical reduction/oxidation and dehalogenation (APEG, BCD or glycolate) are destruction technologies. Soil washing, SVE, and solvent extraction are separation techniques, and Solidification/Stabilization (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 extraction, chemical reduction/oxidation, dehalogenation (APEG, BCD or glycolate), separation, soil washing, and solidification/stabilization. These technologies are discussed in Section 4. Completed ex situ physical/chemical treatment projects for soil, sediment, bedrock and sludge are shown in Table 3-8 and additional information on completed demonstration projects is shown on the FRTR Web Site.

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3.6 Ex Situ Thermal Treatment for Soil, Sediment, Bedrock and Sludge

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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 hot gas decontamination, incineration, open burn/open detonation, pyrolysis, and thermal desorption (high and low). These technologies are discussed in Section4. Completed ex situ thermal treatment projects for soil, sediment, bedrock and sludge are shown in Table 3-9 and additional information on completed demonstration projects are shown on the FRTR Web Site.

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3.7 Containment for Soil, Sediment, Bedrock and Sludge

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Containment treatments are often performed to prevent, or significantly reduce, the migration of contaminants in soils or ground water. Containment is necessary whenever contaminated materials are to be buried or left in place at a site. In general, containment is performed when extensive subsurface contamination at a site precludes excavation and removal of wastes because of potential hazards, unrealistic cost, or lack of adequate treatment technologies.

Containment treatments offer quick installation times and are typically a low to moderate cost treatment group. Unlike ex situ treatment groups, containment does not require excavation of soils, that lead to increased costs from engineering design of equipment, possible permitting, and material handling. However, these treatments require periodical inspections for settlement, ponding of liquids, erosion, and naturally occurring invasion by deep-rooted vegetation. Additionally, ground water monitoring wells, associated with the treatments, need to be periodically sampled and maintained. Even with these long-term requirements containment treatments usually are considerably more economical than excavation and removal of the wastes.

Containment treatments for soil, sediment, bedrock and sludge include landfill cap and landfill cap enhancements. These treatments are discussed in more detail in Section 4. Completed projects for other treatment technologies for soil, sediment, bedrock and sludge are shown in Table 3-10.

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3.8 Other Treatment Technologies for Soil, Sediment, Bedrock and Sludge

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Other treatment technologies for soil, sediment, bedrock and sludge include excavation, retrieval, and off-site disposal. These treatments are discussed in more detail in Section 4. Completed projects for other treatment technologies for soil, sediment, and sludge are shown in Table 3-11.

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3.9 In Situ Biological Treatment for Ground Water, Surface Water, and Leachate

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The main advantage of in situ treatment is that it allows ground water 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 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 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 ground water if no control techniques are used. Typically, to address this issue, bioremediation will be performed above a low permeability soil layer and with ground water monitoring wells downgradient of the remediation area. This type of treatment scheme requires aquifer and contaminant characterization and may still require extracted ground water treatment.

Although not all organic compounds are amenable to biodegradation, bioremediation techniques have been successfully used to remediate ground water 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. They 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 enhanced biodegradation (nitrate and oxygen enhancement with either air sparging or hydrogen peroxide (H_2O_2)), natural attenuation, and phytoremediation of organics. These technologies are discussed in Section 4. Completed in situ biological treatment projects for ground water, surface water, and leachate are shown in Table 3-12 and additional information on completed demonstration

projects are shown on the FRTR Web Site.

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 ground water. 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.

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3.10 In Situ Physical/Chemical Treatment for Ground Water, Surface Water and Leachate

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The main advantage of in situ treatments is that they allow ground water 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), or separate the contamination. Passive treatment walls separate and destroy the contaminant from in situ ground water. Air sparging, directional wells, dual phase extraction, fluid/vapor extraction, and hot water or steam flushing/stripping are separation techniques.

Available in situ physical/chemical treatment technologies include air sparging, bioslurping, directional wells, dual phase extraction, thermal treatment, hydrofracturing, in-well air stripping, and passive/reactive treatment walls. These treatment technologies are discussed in Section 4. Completed in situ physical/chemical treatment projects for ground water, surface water, and leachate are shown in Table 3-13 and additional information on completed demonstration projects are shown on the FRTR Web Site. 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.

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3.11 Ex Situ Biological Treatment for Groundwater, Surface Water, and Leachate

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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 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.

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 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 are bioreactors and constructed wetlands. These technologies are discussed in Section 4. Completed ex situ biological treatment projects for groundwater, surface water, and leachate are shown in Table 3-14 and additional information on completed demonstration projects are shown on the FRTR Web Site.

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3.12 Ex Situ Physical/Chemical Treatment for Ground Water, Surface Water, and Leachate

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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 ground water. Ex situ treatment, however, requires pumping of ground water, 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 adsorption/absorption, advanced oxidation processes, air stripping, granulated activated carbon (GAC)/liquid phase carbon adsorption, ground water pumping, ion exchange, precipitation/coagulation/flocculation, separation, sprinkler irrigation. These technologies are discussed in Section 4. Completed ex situ physical/chemical treatment projects for ground water, surface water, and leachate are shown in Table 3-15 and additional information on completed demonstration projects are shown on the FRTR Web Site.

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3.13 Containment for Ground Water, Surface Water, And Leachate

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Containment measures are often performed to prevent, or significantly reduce, the migration of contaminants in soils or ground water. Containment is necessary whenever contaminated materials are to be buried or left in place at a site. In general, containment is performed when extensive subsurface contamination at a site precludes excavation and removal of wastes because of potential hazards and/or unrealistic cost.

The main advantage of containment methods is that they can prevent further migration of contaminant plumes, and allow for contaminant reduction at sites where the source is undetermined, inaccessible, or where long term remedial actions are being developed. Unlike ex situ treatment groups, containment does not require excavation of contaminated soils, which leads to increased costs from engineering design of equipment, possible permitting, and material handling. However, these treatments require periodical inspections for leaks, ponding of liquids, and corrosion. Additionally, ground water monitoring wells, associated with the treatments, need to be periodically sampled and monitored.

Available containment technologies include physical/biological barriers and deep well injection. These processes are discussed in Section4. Completed containment for ground water, surface water, and leachate projects are shown in Table 3-16.

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3.14 Air Emissions/Off-Gas Treatment

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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 destruction, membrane separation, nonthermal plasma, oxidation, scrubbers, and vapor phase carbon adsorption. These processes are discussed in Section 4 . Completed air emissions/off-gas treatment projects are shown in Table 3-17.

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.1 In Situ Biological Treatment
>>4.1 Bioventing

Introduction>> Oxygen is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.

Description:

Figure 4-1 Typical Bioventing System Bioventing is a promising new technology that stimulates the natural in situ biodegradation of any aerobically degradable compounds in soil by providing oxygen to existing soil microorganisms. In contrast to soil vapor vacuum extraction, bioventing uses low air flow rates to provide only enough oxygen to sustain microbial activity. Oxygen is most commonly supplied through direct air injection into residual contamination in soil. In addition to degradation of adsorbed fuel residuals, volatile compounds are biodegraded as vapors move slowly through biologically active soil.

The U.S. Air Force has produced a technical memorandum which summarizes the results of bioventing treatability studies of fuels conducted at 145 US Air Force sites. The memorandum discusses overall study results and presents cost and performance data and lessons learned.

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

Bioventing is a medium to long-term technology. Cleanup ranges from a few months to several years.

TOP

Synonyms:

DSERTS Code: H11 (Bioventing)

TOP

Applicability:

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

While bioremediation cannot degrade inorganic contaminants, bioremediation can be used to change the valence state of inorganics and cause adsorption, uptake, accumulation, and concentration of inorganics in micro or macroorganisms. These techniques, while still largely experimental, show considerable promise of stabilizing or removing inorganics from soil.

TOP

Limitations:

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

- The water table within several feet of the surface, saturated soil lenses, or low permeability soils reduce bioventing performance.
- Vapors can build up in basements within the radius of influence of air injection wells. This problem can be alleviated by extracting air near the structure of concern.
- Extremely low soil moisture content may limit biodegradation and the effectiveness of bioventing.
- Monitoring of off-gases at the soil surface may be required.
- Aerobic biodegradation of many chlorinated compounds may not be effective unless there is a co-metabolite present, or an anaerobic cycle.
- Low temperatures may slow remediation, although successful remediation has been demonstrated in extremely cold weather climates.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Two basic criteria must be satisfied for successful bioventing. First, air must be able to pass through the soil in sufficient quantities to maintain aerobic conditions; second, natural hydrocarbon-degrading microorganisms must be present in concentrations large enough to obtain reasonable biodegradation rates. Initial testing is designed to determine both air permeability of soil and in situ respiration rates.

Soil grain size and soil moisture significantly influence soil gas permeability. Perhaps the greatest limitation to air permeability is excessive soil moisture. A combination of high water tables, high moisture, and fine-grained soils has made bioventing infeasible at some Air Force test locations.

Several soil characteristics that are known to impact microbial activity are pH, moisture, and basic nutrients, (e.g., nitrogen and phosphorus), and temperature. Soil pH measurements show the optional pH range to be 6 to 8 for microbial activity; however, microbial respiration has been observed at all sites, even in soils that fall outside this optimal range. Optimum soil moisture is very soil-specific. Too much moisture can reduce the air permeability of the soil and decrease its oxygen transfer capability. Too little moisture will inhibit microbial activity. Several Air Force bioventing test sites have sustained biodegradation rates with moisture levels as low as 2 to 5% by weight. However, in extremely arid climates, it may be possible to increase the rate of biodegradation through irrigation, or humidifying the injected air.

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

Hydrocarbon degradation rates are almost always estimated from oxygen utilization rates using a simple stoichiometric relationship with the implicit assumption that all oxygen loss is due to the mineralization of hydrocarbons by microbes. However, simple stoichiometric relationships do not account for biomass production and inorganic oxidation reactions. Oxygen serves a terminal electron acceptor not only in the degradation of organic matter but also in oxidation of reduced inorganic compounds by microorganisms which obtain energy through chemical oxidation. In situ respiration tests can also be taken. Measurement of oxygen utilization in a nearby uncontaminated area is used to account for inorganic oxidation reactions. When used with other indicators of increased microbial activity or biodegradation, respiration tests can provide one of several convergent lines of independent evidence to at least qualitatively document biodegradation.

TOP

Performance Data:

Bioventing is becoming more common, and most of the hardware components are readily available. Bioventing is receiving increased exposure to the remediation consulting community, particularly its use in conjunction with soil vapor extraction (SVE). The Air Force is sponsoring bioventing

demonstrations at 135 sites. As with all biological technologies, the time required to remediate a site using bioventing is highly dependent upon the specific soil and chemical properties of the contaminated media. An overview of this technology, including installation protocols, provided by the Air Force Center for Environmental Excellence (AFCEE) is located at http://www.afcee.brooks.af.mil/er/ert/bioventing.htm.

TOP

Cost:

The key cost driver information and cost analysis was developed using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Surface area is the primary cost driver
  - Impacts the number of injection/extraction wells that are installed. The number of wells installed (and cost) increases with surface area.
- Soil Type
  - Soil types containing sand and gravel produced significantly lower costs by reducing the number of injection/extraction wells that needed to be installed.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply bioventing technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Bioventing			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER CUBIC FOOT	$26	$27	$2	$3
COST PER CUBIC METER	$928	$970	$79	$109
COST PER CUBIC YARD	$709	$742	$60	$84

Detailed Cost Estimate

Other factors that affect the cost of bioventing include contaminant type and concentration, soil permeability, well spacing and number, pumping rate, and off-gas treatment. This technology does not require expensive equipment and relatively few personnel are involved in the operation and maintenance of a bioventing system. Periodic maintenance monitoring is conducted.

TOP

References:

Engineered Approaches to In Situ Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications, July 2000, EPA-542-R-00-008

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Remediation Technology Cost Compendium - Year 2000

Groundwater Cleanup: Overview of Operating Experience at 28 Sites, September 1999, EPA 542-R-99-006,

Treatment Experiences at RCRA Corrective Actions, December 2000, EPA 542-F-00-020

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

Bioventing Performance and Cost Results From Multiple Air Force Test Sites (June 1996)

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Michigan Soil Vapor Extraction Remediation (MISER) Model: A Computer Program to Model Soil Vapor Extraction and Bioventing of Organic Chemicals in Unsaturated Geologic Material (EPA 600-R-97-009)

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CD-ROM of Case Studies: "FRTR Cost and Performance Remediation Case Studies and Related Information"; EPA 542-C-01-003; May 2001.

- Dover Air Force Base, Building 719
- Bioventing Treatment at Refueling Loop E-7, Source Area ST20, Eielson Air Force Base, Alaska
- Low-intensity Bioventing for Remediation of a JP-4 Fuel Spill at Site 280, Hill Air Force Base, Ogden, Utah
- Soil Vapor Extraction and Bioventing for Remediation of a JP-4 Fuel Spill at Site 914, Hill Air Force Base, Ogden, Utah
- Underground Storage Tanks (USTs) Bioventing Treatment at Lowry Air Force Base (AFB), Denver, Colorado
- Multiple Air Force Sites

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USAEC, 1997. "Bioventing of POL Contaminated Soils" in *Innovative Technology Demonstration, Evaluation and Transfer Activities, FY 96 Annual Report,* Report No. SFIM-AEC-ET-CR-97013, pp. 75-76.

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Site Information:

- Chemical Disposal Pit, Hill AFB, UT
- Savannah River
- Air Force Tech Demo
- Tyndall AFB, FL, Armstrong Laboratory/EQW
- Refueling Loop E-7, Source Area ST20, Eielson AFB, AK
- JP-4 Fuel Spill at Site 280, Hill AFB, Ogden, UT
- JP-4 Fuel Spill at Site 914, Hill AFB, Ogden, UT
- Lowry AFB
- DOI Tech Demo: (USGS) Galloway Township, NJ
- Additional Site Information on the FRTR Web Site

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering In Situ Biological Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.1 In Situ Biological Treatment
>>4.2 Enhanced Bioremediation

Introduction>> 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 or immobilization of inorganic contaminants. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials.

Description:

4-2 Typical Enhanced Bioremediation System Enhanced bioremediation is a process in which indigenous or inoculated micro-organisms (e.g., fungi, bacteria, and other microbes) degrade (metabolize) organic contaminants found in soil and/or ground water, converting them to innocuous end products. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials.

➢ *Aerobic*

In the presence of sufficient oxygen (aerobic conditions), and other nutrient elements, microorganisms will ultimately convert many organic contaminants to carbon dioxide, water, and microbial cell mass.

Enhanced bioremediation of soil typically involves the percolation or injection of ground water or uncontaminated water mixed with nutrients and saturated with dissolved oxygen. Sometimes acclimated microorganisms (bioaugmentation) and/or another oxygen source such as hydrogen peroxide are also added. An infiltration gallery or spray irrigation is typically used for shallow contaminated soils, and injection wells are used for deeper contaminated soils.

Although successful in situ bioremediation has been demonstrated in cold weather climate, low temperature slows the remediation process. For contaminated sites with low soil temperature, heat blankets may be used to cover the soil surface to increase the soil temperature and the degradation rate.

Enhanced bioremediation may be classified as a long-term technology which may take several years for cleanup of a plume.

➢ *Anaerobic*

In the absence of oxygen (anaerobic conditions), the organic contaminants will be ultimately metabolized to methane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas. Under sulfate-reduction conditions, sulfate is converted to sulfide or elemental sulfur, and under nitrate-reduction conditions, dinitrogen gas is ultimately produced.

Sometimes contaminants may be degraded to intermediate or final products that may be less, equally, or more hazardous than the original contaminant. For example, TCE anaerobically biodegrades to the persistent and more toxic vinyl chloride. To avoid such problems, most bioremediation projects are conducted *in situ*. Vinyl chloride can easily be broken down further if aerobic conditions are created.

White Rot Fungus

White rot fungus has been reported to degrade a wide variety of organopollutants because of its lignin-degrading or wood-rotting enzymes. Two different treatment configurations have been tested for white rot fungus, in situ and bioreactor. An aerobic system using moisturized air on wood chips is used in a reactor for biodegradation. A reactor was used in the bench-scale trial of the process. In the pilot-scale project, an adjustable shredder was used for making chips for the open system. The open system is similar to composting, with wood chips on a liner or hard contained surface that is covered. Temperature is not controlled in this type of system. The optimum temperature for biodegradation with lignin-degrading fungus ranges from 30 to 38° C (86 to 100° F). The heat of the biodegradation reaction will help to maintain the temperature of the process near the optimum.

Although white rot fungus degradation of TNT has been reported in laboratory-scale settings using pure cultures, several factors increase the difficulty of using this technology for full-scale remediation, and it has not yet been proven successful at this level. These factors include competition from native bacterial populations, toxicity inhibition, chemical sorption, and the inability to meet risk-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 degradation of TNT is attributable to native bacterial populations. High TNT or PCP concentrations in soil also can inhibit growth of white rot fungus. A study suggested that one particular species of white rot fungus 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 onto the fungus and soil amendments, such as corn cobs and straw, rather than actual destruction of TNT. Another study tested a variety of white rot fungus for PCP sensitivity. Eighteen species tested for PCP sensitivity were inhibited by 10 mg per liter of PCP when grown on agar plates. Within 2 weeks, 17 of the 18 species grew in the inhibition zones. In liquid-phase toxicity experiments, all 18 species were killed by 5 mg per liter of PCP.

TOP

Synonyms:

Biostimulation, bioaugmentation, enhanced biodegradation.

DSERTS Codes:

H1 (Bioremediation)
H12 (Bioremediation-In situ)

TOP

Applicability:

Bioremediation techniques have been successfully used to remediate soils, sludges, and ground water contaminated with petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Bench- and pilot-scale studies have demonstrated the effectiveness of anaerobic microbial degradation of nitrotoluenes in soils contaminated with munitions wastes. Bioremediation is especially effective for remediating low level residual contamination in conjunction with source removal.

The contaminant groups treated most often are PAHs, non-halogenated SVOCs (not including PAHs), and BTEX. The types of Superfund sites most commonly treated by bioremediation have been contaminated through processes or wastes associated with wood preserving and petroleum refining and reuse. Wood preserving commonly employs creosote, which has a high concentration of PAHs and other non-halogenated SVOCs. Similarly, petroleum refining and reuse processes frequently involve BTEX.

Because the two contaminant groups most commonly treated using bioremediation are SVOCs (PAHs and other non-halogenated SVOCs), it may be difficult to treat them using technologies that rely on volatility, such as SVE. In addition, bioremediation treatment often does not require heating, requires relatively inexpensive inputs, such as nutrients, and usually does not generate residuals requiring additional treatment or disposal. Also, when conducted in situ, it does not require excavation of contaminated media. Compared with other technologies, such as thermal desorption

and incineration (which require excavation and heating), thermally enhanced recovery (which requires heating), chemical treatment (which may require relatively expensive chemical reagents), and in situ soil flushing (which may require further management of the flushing water), bioremediation may enjoy a cost advantage in the treatment of nonhalogenated SVOCs

While bioremediation (nor any other remediation technology) cannot degrade inorganic contaminants, bioremediation can be used to change the valence state of inorganics and cause adsorption, immobilization onto soil particulates, precipitation, uptake, accumulation, and concentration of inorganics in micro or macroorganisms. These techniques, while still largely experimental, show considerable promise of stabilizing or removing inorganics from soil.

TOP

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-microorganism contact.
- The circulation of water-based solutions through the soil may increase contaminant mobility and necessitate treatment of underlying ground water.
- Preferential colonization by microbes may occur causing clogging of nutrient and water injection wells.
- Preferential flow paths may severely decrease contact between injected fluids and contaminants throughout the contaminated zones. The system should not be used for clay, highly layered, or heterogeneous subsurface environments because of oxygen (or other electron acceptor) transfer limitations.
- High concentrations of heavy metals, highly chlorinated organics, long chain hydrocarbons, or inorganic salts are likely to be toxic to microorganisms.
- Bioremediation slows at low temperatures.
- Concentrations of hydrogen peroxide greater than 100 to 200 ppm in groundwater inhibit the activity of microorganisms.
- A surface treatment system, such as air stripping or carbon adsorption, may be required to treat extracted groundwater prior to re-injection or disposal.

Many of the above factors can be controlled with proper attention to good engineering practice. The length of time required for treatment can range from 6 months to 5 years and is dependent on many site-specific factors.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Important contaminant characteristics that need to be identified in an enhanced bioremediation feasibility investigation are their potential to leach (e.g., water solubility and soil sorption coefficient); their chemical reactivity (e.g., tendency toward nonbiological reactions, such as hydrolysis, oxidation, and polymerization); and, most importantly, their biodegradability.

Soil characteristics that need to be determined include the depth and areal extent of contamination; the concentration of the contaminants; soil type and properties (e.g., organic content, texture, pH, permeability, water-holding capacity, moisture content, and nutrient level); the competition for oxygen (e.g., redox potential); the presence or absence of substances that are toxic to microorganisms; concentration of other electron acceptors, nutrients; and the ability of microorganisms in the soil to degrade contaminants.

Treatability or feasibility tests are performed to determine whether enhanced bioremediation is feasible in a given situation, and to define the remediation time frame and parameters. Field testing can be performed to determine the radius of influence and well spacing and to obtain preliminary cost estimates.

TOP

Performance Data:

The main advantage of the in situ process is that it allows soil to be treated without being excavated and transported, resulting in less disturbance of site activities. If enhanced bioremediation can reach the cleanup goal in a compatible time frame, it can save significant costs over methods involving excavation and transportation. Also, both contaminated ground water and soil can be treated simultaneously, providing additional cost advantages. In situ processes generally require longer time periods, however, and there is less certainty about the uniformity of treatment because of the inherent variability in soil and aquifer characteristics and difficulty in monitoring progress.

Remediation times are often years, depending mainly on the degradation rates of specific contaminants, site characteristics, and climate. Less than one year may be required to clean up some contaminants, but higher molecular weight compounds take longer to degrade.

There is a risk of increasing contaminant mobility and leaching of contaminants into ground water. Regulators often do not accept the addition of nitrates or non-native microorganisms to contaminated soils. Enhanced bioremediation has been selected for remedial and emergency response actions at an increasing number of Superfund sites. Generally, petroleum hydrocarbons can be readily bioremediated, at relatively low cost, by stimulating indigenous microorganisms with nutrients.

TOP

Cost:

Typical costs for enhanced bioremediation range from $30 to $100 per cubic meter ($20 to $80 per cubic yard) of soil. Factors that affect cost include the soil type and chemistry, type and quantity of amendments used, and type and extent of contamination.

Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes (HTRW) Historical Cost Analysis System (HCAS) developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group, as well as the FRTR Cost and Performance Reports.

TOP

References:

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A brief description of the Applicability and Limitations of In situ Enhanced Bioremediation can be found at the NFESC website.

Aggarwal, P.K., J.L. Means, R.E. Hinchee, G.L. Headington, and A.R. Gavaskar, July 1990. *Methods To Select Chemicals for In-Situ Biodegradation of Fuel Hydrocarbons*, Air Force Engineering & Services Center, Tyndall AFB, FL.

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- In Situ Bioremediation Using Horizontal Wells at the U.S. Department of Energy's Savannah River Site, M Area, Aiken, South Carolina

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: In Situ Soil Treatment Technologies (Soil Vapor Extraction, Thermal Processes)*, EPA/542/R-98/012

- Air Sparging, In Situ Bioremediation, and Soil Vapor Extraction at the Texas Tower Site, Fort Greely, Alaska
- Soil Vapor Extraction at the Seymour Recycling Corporation Superfund Site, Seymour, Indiana

Wetzel, R.S., C.M. Durst, D.H. Davidson, and D.J. Sarno, July 1987. "In-Situ Biological Treatment Test at Kelly Air Force Base", *Volume II: Field Test Results and Cost Model*, AD-A187 486, Air Force Engineering & Services Center, Tyndall AFB, FL.

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Site Information:

- Naval Air Station Yorktown, VA
- EPA Remedial Action: Seymour Recycling, IN
- EPA Removal Action: Roseville Drums, CA
- EPA Removal Action: Gila River Indian Reservation, AZ
- EPA Removal Action: Gila River, Indian Reservation, AZ
- Navy Demo: Naval Communication Station, Scotland
- Army Demo: U.S. Army Construction Engineering Research Laboratory, IL
- Air Force Demo: Kelly AFB, TX & Eglin AFB, FL
- FAA Technical Center-Area D Atlantic County, NJ
- Eglin AFB, FL
- Department of Energy's Savannah River Site, M Area, Aiken, South Carolina
- Texas Tower Site, Fort Greely, AK
- Seymour Recycling Corporation Superfund Site, Seymour, IN
- Additional site information on the FRTR web site

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Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.1 In Situ Biological Treatment
>>4.3 Phytoremediation

Introduction>> Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants in soil and sediment. Contaminants may be either organic or inorganic.

Description:

Figure 4-3:
Typical In Situ Phytoremediation System Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants in soil and sediment. The mechanisms of phytoremediation include enhanced rhizosphere biodegradation, phyto-extraction (also called phyto-accumulation), phyto-degradation, and phyto-stabilization.

➢ *Enhanced Rhizosphere Biodegradation*

Enhanced rhizosphere biodegradation takes place in the soil immediately surrounding plant roots. Natural substances released by plant roots supply nutrients to microorganisms, which enhances their biological activities. Plant roots also loosen the soil and then die, leaving paths for transport of water and aeration. This process tends to pull water to the surface zone and dry the lower saturated zones.

The most commonly used flora in phytoremediation projects are poplar trees, primarily because the trees are fastgrowing and can survive in a broad range of climates. In addition, poplar trees can draw large amounts of water (relative to other plant species) as it passes through soil or directly from an aquifer. This may draw greater amounts of dissolved pollutants from contaminated media and reduce the amount of water that may pass through soil or an aquifer, thereby reducing the amount of contaminant flushed though or out of the soil or aquifer.

➢ *Phyto-accumulation*

Phyto-accumulation is the uptake of contaminants by plant roots and the translocation/accumulation (phytoextraction) of contaminants into plant shoots and leaves.

➢ *Phyto-degradation*

Phyto-degradation is the metabolism of contaminants within plant tissues. Plants produce enzymes, such as dehalogenase and oxygenase, that help catalyze degradation. Investigations are proceeding to determine if both aromatic and chlorinated aliphatic compounds are amenable to phyto-degradation.

➢ *Phyto-stabilization*

Phyto-stabilization is the phenomenon of production of chemical compounds by plant to immobilize contaminants at the interface of roots and soil.

Synonyms:

Vegetation-enhanced bioremediation.

TOP

Applicability:

Phytoremediation may be applicable for the remediation of metals, pesticides, solvents, explosives, crude oil, PAHs, and landfill leachates.

Some plant species have the ability to store metals in their roots. They can be transplanted to sites to filter metals from wastewater. As the roots become saturated with metal contaminants, they can be harvested.

Hyper-accumulator plants may be able to remove and store significant amount of metallic contaminants.

Currently, trees are under investigation to determine their ability to remove organic contaminants from ground water, translocate and transpiration, and possibly metabolize them either to CO_2 or plant tissue.

TOP

Limitations:

Limitations to phytoremediation in soil include:

- The depth of the treatment zone is determined by plants used in phytoremediation. In most cases, it is limited to shallow soils.
- High concentrations of hazardous materials can be toxic to plants.
- It involves the same mass transfer limitations as other biotreatments.
- It may be seasonal, depending on location.
- It can transfer contamination across media, e.g., from soil to air.
- It is not effective for strongly sorbed (e.g., PCBs) and weakly sorbed contaminants.
- The toxicity and bioavailability of biodegradation products is not always known.
- Products may be mobilized into ground water or bioaccumulated in animals.
- It is still in the demonstration stage.
- It is unfamiliar to regulators.

TOP

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, detailed information is needed to determine the kinds of soil used for phytoremediation projects. Water movement, reductive oxygen concentrations, root growth, and root structure all affect the growth of plants and should be considered when implementing phytoremediation.

TOP

Performance Data:

Currently, the Superfund Innovative Technology Evaluation (SITE) Program is attempting to demonstrate and evaluate the efficacy and cost of phytoremediation in the field at sites in Oregon, Utah, Texas, and Ohio.

USAEC is also leading the team of experts from EPA, Tennessee Valley Authority (TVA) and the Waterways Experimental Station (WES) to successfully demonstrate phytoremediation of explosive

contaminated sites in Milan Army Ammunition Plant in Milan, TN.

AFCEE is currently conducting several phytoremediation demonstrations, including the following:

A "mature tree" study has been completed at Cape Canaveral Air Station. Live Oak, Saw-tooth Palmetto and Scrub Oak species in the midst of a TCE plume were evaluated for TCE transpiration and TCE transformation rates. Evapotranspiration rates were also measured. Mature trees were used in this study to obviate the waiting period for whips to grow into mature trees.

An initial planting of 110 trees in 1998 was followed by 200 (early 2000) and 150 (spring 2000) additional trees at Travis AFB, CA. The plantings are being used as hydraulic control for a TCE plume. This is a long-term test of the ability of trees to control the movement of groundwater.

A similar study is taking place at Altus AFB, OK. One hundred ten non seed-bearing hybrid cottonwood trees were planted in the fall of 1998. The plantings are being used as hydraulic control for a TCE plume. Soil moisture, groundwater levels, climatic conditions and sap flow rates are monitored remotely in this demonstration. A report on the results of the study will be released in the summer 2001.

A new effort was launched in the summer 2000, with five large-scale plantings planned for Fairchild, Offutt, Hill and Whiteman AFBs. Plantings should be complete by early 2001. More information can also be located at http://www.afcee.brooks.af.mil/er/ert/phytorem.htm.

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Scale of effort
  - Area of contamination is the primary cost driver
- Density of sampling
  - Primary cost driver of sampling cost; may be directed by regulatory requirements.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply phytoremediation technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Phytoremediation			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER SQUARE FOOT	$2	$7	$0.42	$1
COST PER CUBIC FOOT	$18	$66	$4	$14
COST PER CUBIC METER	$626	$2,322	$147	$483
COST PER CUBIC YARD	$479	$1,775	$112	$369

Detailed Cost Estimate

TOP

References:

AFCEE, "An overview of Phytoremediation, including installation protocols", provided by the Air Force Center for Environmental Excellence (AFCEE).

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Treatment Experiences at RCRA Corrective Actions, December 2000, EPA 542-F-00-020

Abstracts of Remediation Case Studies, Volume 4, June 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

Boyajian, G. E. and Devedjian, D. L., 1997. "Phytoremediation: It Grows on You", *Soil & Groundwater Cleanup,* February/March, pp. 22-26.

EPA, 1998. *A Citizen's Guide to Phytoremediation*, Technology Fact Sheet, EPA NCEPI, EPA/542/F-98/011.

EPA, 1996. *A Citizen's Guide to Phytoremediation*, Technology Fact Sheet, EPA NCEPI, EPA/542/F-96/014.

EPA, 1996. *Recent Developments for In Situ Treatment of Metal Contaminated Soils*, EPA/542/R-96/008.

Schnoor, J.L., L.A. Licht, S.C. McCutcheon, N.L. Wolfe, and L.H. Carreira. 1995. "Phytoremediation of organic and nutrient contaminants," *Environ. Sci. Technol.* 29:318A-323A.

USAEC, 1997. "Phytoremediation of Lead" in *Innovative Technology Demonstration, Evaluation and Transfer Activities, FY 96 Annual Report,* Report No. SFIM-AEC-ET-CR-97013, pp. 89-92.

U.S. DOE, 1995. "Bioremediation of High Explosives by Plants," in *Technology Catalogue, Second Edition*, Office of Environmental Management Office of Technology Development, DOE/EM-0235, pp. 169-172.

A comprehensive list of 850 references on phytoremediation are available at Remediation Technologies Development Forum (RTDF) Phytoremediation Action Team Web Site. Click to access

RTDF Phytoremediation Bibliography

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Site Information:

- Trenton, NJ Site
- Dearing, KS
- Whitewood Creek, SD
- Brookhaven National Laboratory
- McCormick & Baxter SUPERFUND Site, Portland, OR (Wood treatment site)
- Argonne National Laboratory
- Craney Island Fuel Terminal, U.S. Navy, Portsmouth, VA
- EPA S.I.T.E. Program, Ogden, Utah

- Ohio (Former metal plating site)
- DOE Demo: Savannah River Site , SC
- DOE Savannah River Site, SC

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering In Situ Biological Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

TOP

To be added

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.10 In Situ Physical/Chemical Treatment
>>4.4 Chemical Oxidation

Introduction>> 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.

Description:

Figure 4-4: Typical Chemical Oxidation System

The Chemical oxidants most commonly employed to date include peroxide, ozone, and permanganate. These oxidants have been able to cause the rapid and complete chemical destruction of many toxic organic chemicals; other organics are amenable to partial degradation as an aid to subsequent bioremediation. In general the oxidants have been capable of achieving high treatment efficiencies (*e.g.*, > 90 percent) for unsaturated aliphatic (*e.g.*, trichloroethylene [TCE]) and aromatic compounds (*e.g.*, benzene), with very fast reaction rates (90 percent destruction in minutes). Field applications have clearly affirmed that matching the oxidant and *in situ* delivery system to the contaminants of concern (COCs) and the site conditions is the key to successful implementation and achieving performance goals.

➢ *Ozone addition*

Ozone gas can oxidize contaminants directly or through the formation of hydroxyl radicals. Like peroxide, ozone reactions are most effective in systems with acidic pH. The oxidation reaction proceeds with extremely fast, pseudo first order kinetics. Due to ozone's high reactivity and instability, O_3 is produced onsite, and it requires closely spaced delivery points (*e.g.*, air sparging wells). *In situ* decomposition of the ozone can lead to beneficial oxygenation and biostimulation.

➢ *Peroxide*

Oxidation using liquid hydrogen peroxide (H_2O_2) in the presence of native or supplemental ferrous iron (Fe^{+2}) produces Fenton's Reagent which yields free hydroxyl radicals (OH^-). These strong, nonspecific oxidants can rapidly degrade a variety of organic compounds. Fenton's Reagent oxidation is most effective under very acidic pH (e.g., pH 2 to 4) and becomes ineffective under moderate to strongly alkaline conditions. The reactions are extremely rapid and follow second-order kinetics.

➢ *Permanganate*

The reaction stoichiometry of permanganate (typically provided as liquid or solid $KMnO_4$, but also available in Na, Ca, or Mg salts) in natural systems is complex. Due to its multiple valence states and mineral forms, Mn can participate in numerous reactions. The reactions proceed at a somewhat slower rate than the previous two reactions, according to second order kinetics. Depending on pH, the reaction can include destruction by direct electron transfer or free radical advanced oxidation—permanganate reactions are effective over a pH range of 3.5 to 12.

Synonyms:

DSERTS Code: N13 (Chemical Reduction/Oxidation).

TOP

Applicability:

The rate and extent of degradation of a target COC are dictated by the properties of the chemical itself and its susceptibility to oxidative degradation as well as the matrix conditions, most notably, pH, temperature, the concentration of oxidant, and the concentration of other oxidant-consuming substances such as natural organic matter and reduced minerals as well as carbonate and other free radical scavengers. Given the relatively indiscriminate and rapid rate of reaction of the oxidants with reduced substances, the method of delivery and distribution throughout a subsurface region is of paramount importance. Oxidant delivery systems often employ vertical or horizontal injection wells and sparge points with forced advection to rapidly move the oxidant into the subsurface.

Permanganate is relatively more stable and relatively more persistent in the subsurface; as a result, it can migrate by diffusive processes. Consideration also must be given to the effects of oxidation on the system. All three oxidation reactions can decrease the pH if the system is not buffered effectively. Other potential oxidation-induced effects include: colloid genesis leading to reduced permeability; mobilization of redox-sensitive and exchangeable sorbed metals; possible formation of toxic byproducts; evolution of heat and gas; and biological perturbation

TOP

Limitations:

The following factors may limit the applicability and effectiveness of chemcial oxidation include:

- Requirement for handling large quantities of hazardous oxidizing chemicals due to the oxidant demand of the target organic chemicals and the unproductive oxidant consumption of the formation.
- Some COCs are resistant to oxidation.
- There is a potential for process-induced detrimental effects. Further research and development is ongoing to advance the science and engineering of *in situ* chemical oxidation and to increase its overall cost effectivenes.

TOP

Data Needs:

Engineering of *in situ* chemical oxidation must be done with due attention paid to reaction chemistry and transport processes. It is also critical that close attention be paid to worker training and safe handling of process chemicals as well as proper management of remediation wastes. The design and implementation process should rely on an integrated effort involving screening level characterization tests and reaction transport modeling, combined with treatability studies at the lab and field scale.

TOP

Performance Data:

In situ chemical oxidation is a viable remediation technology for mass reduction in source areas as well as for plume treatment. The potential benefits of *in situ* oxidation include the rapid and extensive reactions with various COCs applicable to many bio-recalcitrant organics and subsurface environments. Also, *in situ* chemical oxidation can be tailored to a site and implemented with relatively simple, readily available equipment. Some potential limitations exist including the requirement for handling large quantities of hazardous oxidizing chemicals due to the oxidant

demand of the target organic chemicals and the unproductive oxidant consumption of the formation; some COCs are resistant to oxidation; and there is a potential for process-induced detrimental effects. Further research and development is ongoing to advance the science and engineering of *in situ* chemical oxidation and to increase its overall cost effectiveness

TOP

Cost:

No costs figures are currently available.

TOP

References:

EPA, 2000.Ground Water Currents, December 2000, Issue No. 41: Current Issue: Interagency Demonstrations on DNAPL Conducted at Cape Canaveral

EPA, 2000.Ground Water Currents, September 2000, Issue No. 37: Current Issue: *In Situ* Chemical Oxidation for Remediation of Contaminated Soil and Ground Water

MTBE Treatment Case Studies presented by the USEPA Office of Underground Storage Tanks.

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

Abstracts of Remediation Case Studies, Volume 4, June 2000,EPA 542-R-00-006

Advanced Photochemical Oxidation - Abstract, EPA/625/R-98/004

EPA, 1988, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, OSWER- 9355.3-01, Washington, DC

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Site Information:

- Additional site information on the FRTR web site

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering In Situ Physical/Chemical Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and

their applications.

Government Disclaimer

Health and Safety:

TOP

Hazard Analysis

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.2 In Situ Physical/Chemical Treatment
>>4.5 Electrokinetic Separation

Introduction>> The Electrokinetic Remediation (ER) process removes metals and organic contaminants from low permeability soil, mud, sludge, and marine dredging. ER uses electrochemical and electrokinetic processes to desorb, and then remove, metals and polar organics. This in situ soil processing technology is primarily a separation and removal technique for extracting contaminants from soils.

Description:

Figure 4-5: Typical In Situ Electrokinetic Separation System The principle of electrokinetic remediation relies upon application of a low-intensity direct current through the soil between ceramic electrodes that are divided into a cathode array and an anode array. This mobilizes charged species, causing ions and water to move toward the electrodes. Metal ions, ammonium ions, and positively charged organic compounds move toward the cathode. Anions such as chloride, cyanide, fluoride, nitrate, and negatively charged organic compounds move toward the anode. The current creates an acid front at the anode and a base front at the cathode. This generation of acidic condition in situ may help to mobilize sorbed metal contaminants for transport to the collection system at the cathode.

The two primary mechanisms transport contaminants through the soil towards one or the other electrodes: electromigration and electroosmosis. In electromigration, charged particles are transported through the substrate. In contrast, electroosmosis is the movement of a liquid containing ions relative to a stationary charged surface. Of the two, electromigration is the main mechanism for the ER process. The direction and rate of movement of an ionic species will depend on its charge, both in magnitude and polarity, as well as the magnitude of the electroosmosis-induced flow velocity. Non-ionic species, both inorganic and organic, will also be transported along with the electroosmosis induced water flow.

Two approaches are taken during electrokinetic remediation: "Enhanced Removal" and "Treatment without Removal".

"Enhanced Removal" is achieved by electrokinetic transport of contaminants toward the polarized electrodes to concentrate the contaminants for subsequent removal and ex-situ treatment. Removal of contaminants at the electrode may be accomplished by several means among which are: electroplating at the electrode; precipitation or co-precipitation at the electrode; pumping of water near the electrode; or complexing with ion exchange resins. Enhanced removal is widely used on remediation of soils contaminated metals.

"Treatment without Removal" is achieved by electro-osmotic transport of contaminants through treatment zones placed between electrodes. The polarity of the electrodes is reversed periodically, which reverses the direction of the contaminants back and forth through treatment zones. The frequency with which electrode polarity is reversed is determined by the rate of transport of contaminants through the soil. This approach can be used on in-situ remediation of soils contaminated with organic species.

TOP

Synonyms:

Electrokinetics; Electromigration.

TOP

Applicability:

Targeted contaminants for electrokinetics are heavy metals, anions, and polar organics in soil, mud, sledge, and marine dredging. Concentrations that can be treated range from a few parts per million (ppm) to tens of thousands ppm. Electrokinetics is most applicable in low permeability soils. Such soils are typically saturated and partially saturated clays and silt-clay mixtures, and are not readily drained.

TOP

Limitations:

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

- Effectiveness is sharply reduced for wastes with a moisture content of less than 10 percent. Maximum effectiveness occurs if the moisture content is between 14 and 18 percent.
- The presence of buried metallic or insulating material can induce variability in the electrical conductivity of the soil, therefore, the natural geologic spatial variability should be delineated. Additionally, deposits that exhibit very high electrical conductivity, such as ore deposits, cause the technique to be inefficient.
- Inert electrodes, such as carbon, graphite, or platinum, must be used so that no residue will be introduced into the treated soil mass. Metallic electrodes may dissolve as a result of electrolysis and introduce corrosive products into the soil mass.
- Electrokinetics is most effective in clays because of the negative surface charge of clay particles. However, the surface charge of the clay is altered by both charges in the pH of the pore fluid and the adsorption of contaminants. Extreme pH at the electrodes and reduction-oxidation changes induced by the process electrode reactions many inhibit ER's effectiveness, although acidic conditions (i.e., low pH) may help to remove metals.
- Oxidation/reduction reactions can form undesirable products (e.g., chlorine gas).

TOP

Data Needs:

A detailed discussion of data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment and Sludge).

TOP

Performance Data:

There have been few, if any, commercial applications of electrokinetic remediation in the United States. The electrokinetic technology has been operated for test and demonstration purposes at the pilot scale and at full scale at the following sites: (1) Louisiana State University, (2) Electrokinetics, Inc., (3) Geokinetics International, Inc., and (4) Battelle Memorial Institute. Geokinetics International, Inc.(GII) has successfully demonstrated the in situ electrokinetic remediation process in five field sites in Europe.

In 1996, a comprehensive demonstration study of lead extraction at a U.S.Army firing range in Louisiana was conducted by DoD's Small Business Innovative Research Program and Electrokinetics, Inc. The EPA taking part in independent assessments of the results, found pilot-scale studies have demonstrated that concentrations of lead decreased to less than 300 mg/kg in 30 weeks of electrokinetic processing when the soils where originally contaminated as high as 4,500 mg/kg of lead.

TOP

Cost:

Costs will vary with the amount of soil to be treated, the conductivity of the soil, the type of contaminant, the spacing of electrodes, and the type of process design employed. Ongoing pilot-scale studies using "real-world" soils indicate that the energy expenditures in extraction of metals from soils may be 500 kWh/m^3 or more at electrode spacing of 1.0m to 1.5m. Direct costs estimates of about \$15/m^3 for a suggested energy expenditure of \$0.03 per kilowatt hours, together with the cost of enhancement, could result in direct costs of \$50/m^3 or more. A recent study estimated full scale costs at \$117 per cubic meter. If no other efficient in situ technology is available to remediate fine-grained and heterogeneous subsurface deposits contaminated with metals, this technique would remain potentially competitive.

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

EPA, 1996. *Recent Development for In Situ Treatment of Metal Contaminated Soil,* EPA Office of Solid Waste & Emergency Response. Technology Innovative Office. Washington, DC.

USAEC, 1997. "In-situ Electrokinetic Remediation for Metal Contaminated Soils" in *Innovative Technology Demonstration, Evaluation and Transfer Activities, FY 96 Annual Report,* Report No. SFIM-AEC-ET-CR-97013, pp. 87-88.

U.S. DOE, 1995. "Electrokintic Remediation of Heavy Metals and Radionuclides," in *Technology Catalogue, Second Edition*, Office of Environmental Management Office of Technology Development, DOE/EM-0235, pp. 201-203.

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Site Information:

- Army Demo, U.S. Army Waterways Experiment Station, Baton Rouge Louisiana
- An Underground Storage Tank Spill
- DOE Demo, Oak Ridge K-25 facility, Tennessee
- DOE Demo: Sandia National Laboratories Chemical Waste Landfill
- EPA/DOE Demo: DOE Gaseous Diffusion Plant, Paducah, Kentucky
- DOE Demo, Old TNX Basin, Savannah River Site, South Carolina
- U.S. Army, firing range, LA
- Additional site information on the FRTR web site

Points of Contact:

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Technology Specific Web Sites:

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Vendor Information:

A list of vendors offering In Situ Physical/Chemical Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

TOP

To be added

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.2 In Situ Physical/Chemical Treatment
>>4.6 Fracturing

Introduction>> Cracks are developed by fracturing beneath the surface in low permeability and over-consolidated sediments to open new passageways that increase the effectiveness of many in situ processes and enhance extraction efficiencies.

Description:

Figure 4-6: Typical Pneumatic Fracturing Process Fracturing is an enhancement technology designed to increase the efficiency of other in situ technologies in difficult soil conditions. The fracturing extends and enlarges existing fissures and introduces new fractures, primarily in the horizontal direction. When fracturing has been completed, the formation is then subjected to vapor extraction, either by applying a vacuum to all wells or by extracting from selected wells, while other wells are capped or used for passive air inlet or forced air injection. Technologies commonly used in soil fracturing include pneumatic fracturing (PF), blast-enhanced fracturing and Lasagna™ process.

➢ *Blast-enhanced Fracturing*

Blast-enhanced fracturing is a process used at sites with fractured bedrock formations. The increased well yields, hydraulic conductivity values, and capture zones occur as a result of the highly fractured area created by detonation of explosives in boreholes.

➢ *Lasagna™ Process*

Lasagna™ is an integrated, in situ remedial technology, which combines electroosmosis with treatment zones that are installed directly in the contaminated soil. In Lasagna™ process, hydraulic fracturing is used to create sorption/degradation zones horizontally in the subsurface soil.

➢ *Pneumatic Fracturing (PF)*

In the PF process, fracture wells are drilled in the contaminated vadose zone and left open (uncased) for most of their depth. A packer system is used to isolate small (0.6-meter or 2-foot) intervals so that short bursts (~20 seconds) of compressed air (less than 10,300 mmHg or 200 pounds per square inch) can be injected into the interval to fracture the formation. The process is repeated for each interval within the contaminated depth.

TOP

Synonyms:

DSERTS Code: M15 (Pneumatic Fracturing Enhancement).

TOP

Applicability:

Fracturing is applicable to the complete range of contaminant groups with no particular target group. The technology is used primarily to fracture silts, clays, shale, and bedrock.

TOP

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 required.
- The potential exists to open new pathways for the unwanted spread of contaminants (e.g., dense nonaqueous phase liquids).

TOP

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 depth and areal extent of contamination, the concentration of the contaminants, and soil type and properties (e.g., structure, organic content, texture, permeability, water-holding capacity, and moisture content).

TOP

Performance Data:

The technology is currently available from only one vendor. PF was tested with hot gas injection and extraction in EPA's SITE demonstration program in 1992. Results indicate that PF increased the effective vacuum radius of influence nearly threefold and increased the rate of mass removal up to 25 times over the rates measured using conventional extraction technologies. A Phase II demonstration is planned for 1994. The technology has been demonstrated in the field, including the one under EPA's SITE program. In addition, numerous bench-scale and theoretical studies have been published.

During the summer of 1993, a pilot demonstration of pneumatic fracturing was sponsored by DOE at Tinker AFB to enhance remediation of the fine-grained silts, clays, and sedimentary rock that underlie the site. At one test area, where No. 2 fuel oil was being pumped from existing recovery wells, pneumatic fracturing increased the average monthly removal rate by 15 times. Tests conducted in the unsaturated zone also showed enhanced air permeability as a result of 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 fracture radius of 4 to 6 meters (15 to 20 feet) to a depth of 15 to 30 meters (50 to 100 feet). For longer remediation programs, refracturing efforts may be required at 6- to 12-month intervals.

TOP

Cost:

The approximate cost range for pneumatic fracturing is $9 to $13 per metric ton ($8 to $12 per ton).

Cost for Lasagna™ is estimated at $180 to $200 per metric ton ($160 to $180 per ton) for remediation in 1 year, $110 to $130 per metric ton ($100 to $120 per ton) if 3 years are allowed for remediation.

TOP

References:

Link to the U.S. Environmental Protection Agency's Technology Innovation Office (TIO) website which contains information related to identifying and remediating contaminated fractured rock sites.

Athmer, C. J. et al., 1996, *Large Scale Field Test of Lasagna Process*, Remediation Technologies Development Forum Topical Report, DOE/METC/31185-5390, DE97002156.

California Base Closure Environmental Committee (CBCEC), 1994. *Treatment Technologies Applications Matrix for Base Closure Activities, Revision 1*, Technology Matching Process Action Team, November, 1994.

EPA, 1993. *Accutech Pneumatic Fracturing Extraction and Hot Gas Injection, Phase I*, EPA RREL; series includes Technology Evaluation, EPA/540/R-93/509; Technology Demonstration Summary, EPA/540/ SR-93/509; Demonstration Bulletin, EPA/540/MR-93/509; and Applications Analysis, EPA/540/AR-93/509.

EPA, 1993. "Pneumatic Fracturing Increases VOC Extractor Rate," *Tech Trends*, EPA Report, EPA/542/N-93/010.

EPA, 1995. *In Situ Remediation Technology Status Report: Hydraulic and Pneumatic Fracturing*, EPA/542/K-94/005.

EPA, 1996. *Lasagna™ Public-Private Partnership*, EPA Report EPA/542/F-96/010A.

EPA, 1997. *Analysis of Selected Enhancements for Soil Vapor Extraction*, EPA OSWER, EPA/542/R-97/007.

Federal Remediation Technologies Roundtable, 1997. *Remediation Case Studies: Bioremediation and Vitrification*, EPA/542/R-97/008.

- Lasagna™ Soil Remediation at the U.S. Department of Energy's Paducah Gaseous Diffusion Plant, Cylinder Drop Test Area, Paducah, Kentucky

Federal Remediation Technologies Roundtable, 1997. *Remediation Case Studies: Soil Vapor Extraction and Other In Situ Technologies*, EPA/542/R-97/009.

- Hydraulic and Pneumatic Fracturing at the U.S. Department of Energy's Portsmouth Gaseous Diffusion Plant, Ohio; Department of Defense; and Commercial Sites.

Miller, R. R., 1996. *Artificially-Induced or Blast-Enhanced Fracturing*, Ground-Water Remediation Technologies Analysis Center, Technology Overview Report TO-96-01.

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Site Information:

- EPA Demo: NJDEPE-ECRA Site, NJ
- EPA Demo: Oak Brook, IL & Dayton, OH
- Marcus Hook, PA
- DOE's Portsmouth Gaseous Diffusion Plant, OH
- DOE's Paducah Gaseous Diffusion Plant, Cylinder Drop Test Area, Paducah, KY
- Additional site information on the FRTR web site

Points of Contact:

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Technology Specific Web Sites:

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Vendor Information:

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Government Disclaimer

Health and Safety:

TOP

To be added.

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.2 In Situ Physical/Chemical Treatment
>>4.7 Soil Flushing

Introduction>> Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the ground water to raise the water table into the contaminated soil zone. Contaminants are leached into the ground water, which is then extracted and treated.

Description:

Figure 4-7:
Typical Soil Flushing System In situ soil flushing is the extraction of contaminants from the soil with water or other suitable aqueous solutions. Soil flushing is accomplished by passing the extraction fluid through in-place soils using an injection or infiltration process. Extraction fluids must be recovered from the underlying aquifer and, when possible, they are recycled.

➢ *Cosolvent Enhancement*

Cosolvent flushing involves injecting a solvent mixture (e.g., water plus a miscible organic solvent such as alcohol) into either vadose zone, saturated zone, or both to extract organic contaminants. Cosolvent flushing can be applied to soils to dissolve either the source of contamination or the contaminant plume emanating from it. The cosolvent mixture is normally injected upgradient of the contaminated area, and the solvent with dissolved contaminants is extracted downgradient and treated above ground.

Recovered ground water and flushing fluids with the desorbed contaminants may need treatment to meet appropriate discharge standards prior to recycle or release to local, publicly owned wastewater treatment works or receiving streams. To the maximum extent practical, recovered fluids should be reused in the flushing process. The separation of surfactants from recovered flushing fluid, for reuse in the process, is a major factor in the cost of soil flushing. Treatment of the recovered fluids results in process sludges and residual solids, such as spent carbon and spent ion exchange resin, which must be appropriately treated before disposal. Air emissions of volatile contaminants from recovered flushing fluids should be collected and treated, as appropriate, to meet applicable regulatory standards. Residual flushing additives in the soil may be a concern and should be evaluated on a site-specific basis.

The duration of soil flushing process is generally short- to medium-term.

TOP

Synonyms:

Cosolvents Enhancement; Surfactant Flooding.

DSERTS Code: M12 (Soil Flushing).

TOP

Applicability:

The target contaminant group for soil flushing is inorganics including radioactive contaminants. The technology can be used to treat VOCs, SVOCs, fuels, and pesticides, but it may be less cost-effective than alternative technologies for these contaminant groups. The addition of environmentally compatible surfactants may be used to increase the effective solubility of some organic compounds; however, the flushing solution may alter the physical/chemical properties of the soil system. The technology offers the potential for recovery of metals and can mobilize a wide range of organic and inorganic contaminants from coarse-grained soils.

TOP

Limitations:

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

- Low permeability or heterogeneous 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 introduction of surfactants to the subsurface concern regulators. The technology should be used only where flushed contaminants and soil flushing fluid can be contained and recaptured.
- Aboveground separation and treatment costs for recovered fluids can drive the economics of the process.

TOP

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 are required to determine the feasibility of the specific soil-flushing process being considered. Physical and chemical soil characterization parameters that should be established include soil permeability, soil structure, soil texture, soil porosity, moisture content, total organic carbon (TOC), cation exchange capacity (CEC), pH, and buffering capacity.

Contaminant characteristics that should be established include concentration, solubility, partition coefficient, solubility products, reduction potential, and complex stability constants. Soil and contaminant characteristics will determine the flushing fluids required, flushing fluid compatibility, and changes in flushing fluids with changes in contaminants.

TOP

Performance Data:

Soil flushing is a developing technology that has had limited use in the United States. Typically, laboratory and field treatability studies must be performed under site-specific conditions before soil flushing is selected as the remedy of choice. To date, the technology has been selected as part of the source control remedy at 12 Superfund sites. This technology is currently operational at only one Superfund site; a second was scheduled to begin operation in 1991. EPA completed construction of a mobile soil-flushing system, the In Situ Contaminant/Treatment Unit, in 1988. This mobile soil-flushing system is designed for use at spills and uncontrolled hazardous waste sites. There has been very little commercial success with this technology.

TOP

Cost:

The key cost driver information and cost analysis was developed using the 2006 version of the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Soil Permeability
    - The primary cost driver is soil permeability. Soils with lower permeability are more recalcitrant to soil flushing thus remediation time can be significantly increased which increases costs.
- Depth to Groundwater
    - Depth to groundwater is the secondary cost driver, with a deeper water table causing a higher cost to complete.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply soil flushing technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Soil Flushing			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
CUBIC YARDS PROCESSED	1,388	1,388	5,550	5,550
COST PER CUBIC YARD	$32	$49	$18	$27
COST PER 1000 CUBIC YARDS	$32,320	$48,729	$18,420	$26,853

Detailed Cost Estimate

TOP

References:

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Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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Site Information:

- Laramie Tie Plant, WY

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Vendor Information:

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A list of vendors offering In Situ Physical/Chemical Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.2 In Situ Physical/Chemical Treatment
>>4.8 Soil Vapor Extraction

Introduction>> Vacuum is applied through extraction wells to create a pressure/concentration gradient that induces gas-phase volatiles to be removed from soil through extraction wells. This technology also is known as in situ soil venting, in situ volatilization, enhanced volatilization, or soil vacuum extraction.

Description:

Figure 4-8:
Typical In Situ Soil Vapor Extraction System 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. 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.

For the soil surface, geomembrane covers are often placed over soil surface to prevent short circuiting and to increase the radius of influence of the wells.

Ground water depression pumps may be used to reduce ground water upwelling induced by the vacuum or to increase the depth of the vadose zone. Air injection is effective for facilitating extraction of deep contamination, contamination in low permeability soils, and contamination in the saturated zone (see Treatment Technology Profile 4.32, Air Sparging).

The duration of operation and maintenance for in situ SVE is typically medium- to long-term.

TOP

Synonyms:

In situ soil venting; In situ volatilization; Enhanced volatilization.
DSERTS Code: M11 (Soil Vapor Extraction).

TOP

Applicability:

The target contaminant groups for in situ SVE are VOCs and some fuels. The technology is typically applicable only to volatile compounds with a Henry's law constant greater than 0.01 or a vapor pressure greater than 0.5 mm Hg (0.02 inches Hg). Other factors, such as the moisture content, organic content, and air permeability of the soil, will also affect in situ SVE's effectiveness. In situ SVE will not remove heavy oils, metals, PCBs, or dioxins. Because the process involves the continuous flow of air through the soil, however, it often promotes the in situ biodegradation of low-volatility organic compounds that may be present.

Limitations:

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

- Soil that has a high percentage of fines and a high degree of saturation will require higher vacuums (increasing costs) and/or hindering the operation of the in situ SVE system.
- Large screened intervals are required in extraction wells for soil with highly variable permeabilities or stratification, which otherwise may result in uneven delivery of gas flow from the contaminated regions.
- Soil that has high organic content or is extremely dry has a high sorption capacity of VOCs, which results in reduced removal rates.
- Exhaust air from in situ SVE system may require treatment to eliminate possible harm to the public and the environment.
- As a result of off-gas treatment, residual liquids may require treatment/disposal. Spent activated carbon will definitely require regeneration or disposal.
- SVE is not effective in the saturated zone; however, lowering the water table can expose more media to SVE (this may address concerns regarding LNAPLs).

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Data requirements include the depth and areal extent of contamination, the concentration of the contaminants, depth to water table, and soil type and properties (e.g., structure, texture, permeability, and moisture content).

Pilot studies should be performed to provide design information, including extraction well, radius of influence, gas flow rates, optimal applied vacuum, and contaminant mass removal rates.

TOP

Performance Data:

A field pilot study is necessary to establish the feasibility of the method as well as to obtain information necessary to design and configure the system. During full-scale operation, in situ SVE can be run intermittently (pulsed operation) once the extracted mass removal rate has reached an asymptotic level. This pulsed operation can increase the cost-effectiveness of the system by facilitating extraction of higher concentrations of contaminants. After the contaminants are removed by in situ SVE, other remedial measures, such as biodegradation, can be investigated if remedial action objectives have not been met. In situ SVE projects are typically completed in 1 to 3 years.

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Economy of Scale
  - Quantity of material treated has a large impact
- Soil Type
  - Based on the number of wells required
- Can be radically different if no airflow treatment is required

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply soil vapor extraction technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Soil Vapor Extraction			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER CUBIC FOOT	$36	$42	$11	$27
COST PER CUBIC METER	$1,275	$1,485	$405	$975
COST PER CUBIC YARD	$944	$1,100	$300	$722

Detailed Cost Estimate

The cost of in situ SVE is site-specific, depending on the size of the site, the nature and amount of contamination, and the hydrogeological setting (EPA, July 1989). These factors affect the number of wells, the blower capacity and vacuum level required, and the length of time required to remediate the site. A requirement for off-gas treatment adds significantly to the cost. Water is also frequently extracted during the process and usually requires treatment prior to disposal, further adding to the cost.

TOP

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- Soil Vapor Extraction and Bioventing for Remediation of a JP-4 Fuel Spill at Site 914, Hill Air Force Base, Ogden, Utah

Federal Remediation Technologies Roundtable, 1995. *Remediation Case Studies: Groundwater Treatment*, EPA/542/R-95/003.

- Density-Driven Groundwater Sparging at Amcor Precast Ogden, Utah

Federal Remediation Technologies Roundtable, 1995. *Remediation Case Studies: Soil Vapor Extraction*, EPA/542/R-95/004.

- Soil Vapor Extraction System at Commencement Bay, South Tacoma Channel (Well 12A), Phase 2, Tacoma, Washington
- Soil Vapor Extraction at the Fairchild Semiconductor Corporation Superfund Site, San Jose, California
- Soil Vapor Extraction at the Hastings Groundwater Contamination Superfund Site, Well Number 3 Subsite, Hastings, Nebraska
- Soil Vapor Extraction at the North Fire Training Area (NFTA), Luke AFB, Arizona
- In Situ Soil Vapor Extraction at McClellan Air Force Base, California
- Soil Vapor Extraction at the Rocky Mountain Arsenal Superfund Site, Motor Pool Area (OU 18), Commerce City, Colorado
- Soil Vapor Extraction at the Sacramento Army Depot Superfund Site, Tank 2, Operable Unit 3, Sacramento, California
- Soil Vapor Extraction at the SMS Instruments Superfund Site, Deer Park, New York
- Soil Vapor Extraction at the Verona Well Field Superfund Site, Thomas Solvent Raymond Road (OU-1), Battle Creek, Michigan

Federal Remediation Technologies Roundtable, 1997. *Remediation Case Studies: Soil Vapor Extraction and Other In Situ Technologies*, EPA/542/R-97/009.

- Soil Vapor Extraction at the Sacramento Army Depot Superfund Site, Burn Pits Operable Unit, Sacramento, California
- Soil Vapor Extraction at the Sand Creek Industrial Superfund Site, Operable Unit No. 1, Commerce City, Colorado

- In Situ Enhanced Soil Mixing at the U.S. Department of Energy's Portsmouth Gaseous Diffusion Plant, X-231B Unit, Piketon, Ohio

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- Soil Vapor Extraction at Camp LeJeune Military Reservation, Site 82, Area A, Onslow County, North Carolina
- Soil Vapor Extraction at Site ST-35, Davis-Monthan AFB, Arizona
- Soil Vapor Extraction at Defense Supply Center Richmond, OU 5, Chesterfield County, Virginia
- Air Sparging, In Situ Bioremediation, and Soil Vapor Extraction at the Texas Tower Site, Fort Greely, Alaska
- Air Sparging and Soil Vapor Extraction at Landfill 4, Fort Lewis, Washington
- Soil Vapor Extraction at Fort Richardson, Building 908 South, Anchorage, Alaska
- Soil Vapor Extraction at Sites 2 and 5, Holloman AFB, New Mexico
- Soil Vapor Extraction at the Intersil/Siemens Superfund Site, Cupertino, California
- Soil Vapor Extraction at the Seymour Recycling Corporation Superfund Site, Seymour, Indiana
- Soil Vapor Extraction and Groundwater Containment at OU1, Shaw AFB, South Carolina
- Soil Vapor Extraction at the Tyson's Dump Superfund Site, Upper Merion Township, Pennsylvania

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Groundwater Pump and Treat (Chlorinated Solvents)*, EPA/542/R-98/013

- Groundwater Pump and Treat and Soil Vapor Extraction at DOE's Lawrence Livermore National Laboratory, Site 300, GSA OU, Livermore, California
- Pump and Treat of Contaminated Groundwater at the Mystery Bridge at Hwy 20 Superfund Site, Dow/DSI Facility, Evansville, Wyoming

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Groundwater Pump and Treat (Nonchlorinated Solvents)*, EPA/542/R-98/014

- Pump and Treat and Containment of Contaminated Groundwater at the Sylvester/Gilson Road Superfund Site, Nashua, New Hampshire

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Innovative Groundwater Treatment Technologies*, EPA/542/R-98/015.

- Pump and Treat, In Situ Bioremediation, and In Situ Air Sparging of Contaminated Groundwater at Site A, Long Island, New York

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Site Information:

- EPA Remedial Action: Fair Child Semiconductor, San Jose, CA
- EPA Remedial Action Hollingsworth Solderless, FL
- EPA Removal Action: Hinson Chemical, SC
- EPA Removal Action: CSX McCormick Derailment Site, SC
- DOE Demo: Savannah River Site, SC
- Air Force Demo: Hill AFB, UT
- Army Demo: Twin Cities AAP, MN
- EPA Demo: Superfund Sites, Puerto Rico & Massachusetts
- Army Demo: Luke AFB, AZ
- EPA Demo: Buchanan, MI
- DOE Demo: LLNL, CA
- Army Demo: Sacramento Army Depot, CA
- Groveland Wells Superfund Site Groveland, MA
- Letterkenny AD Chambersburg, PA
- Camp LeJeune Military Reservation, Site 82, Area A, Onslow County, NC
- Commencement Bay, South Tacoma Channel (Well 12), Phase 2, Tacoma, WA

- Site ST-35, Davis-Monthan AFB, AZ
- Defense Supply Center Richmond, OU 5, Chesterfield County, VA
- Fairchild Semiconductor Corporation Superfund Site, San Jose, CA
- Texas Tower Site, Fort Greely, AK
- Landfill 4, Fort Lewis, WA
- Fort Richardson, Building 908 South, Anchorage, AK
- Hastings Ground Water Contamination Superfund Site, Well #3 Subsite, Hastings, NE
- JP-4 Fuel Spill at Site 914, Hill AFB, Ogden, UT
- Sites 2 and 5, Holloman AFB, NM
- Intersil/Siemens Superfund Site, Cupertino, CA
- North Fire Training Area (NFTA), Luke AFB, AZ
- McClellan AFB, Operable Unit D, Site S, CA
- Rocky Mountain Arsenal Superfund Site, Motor Pool Area (OU 18), Commerce City, CO
- Sacramento Army Depot Superfund Site, Burn Pits Operable Unit, Sacramento, CA
- Sacramento Army Depot Superfund Site, Tank 2, Operable Unit 3, Sacramento, CA
- Sand Creek Industrial Superfund Site, Operable Unit No. 1, Commerce City, CO
- Seymour Recycling Corporation Superfund Site, Seymour, IN
- OU1, Shaw AFB, SC
- SMS Instruments Superfund Site, Deer Park, NY
- Tyson's Dump Superfund Site, Upper Merion Township, PA
- DOE's Portsmouth Gaseous Diffusion Plant, X-231B Unit, Piketon, OH
- Verona Wellfield Field superfund Site, Thomas Solvent Raymond Road (OU-1), Battle Creek, MI
- Amcor Precast Ogden, UT
- DOE's Lawrence Livermore National Laboratory, Site 300, GSA OU, Livermore, CA
- Mystery Bridge at Hwy 20 Superfund Site, Dow/DSI Facility, Evansville, WY
- Site A, Long Island, NY
- Sylvester/Gilson Road Superfund Site, Nashua, NH
- Additional site information on the FRTR web site

Points of Contact:

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Technology Specific Web Sites:

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A list of vendors offering In Situ Physical/Chemical Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.2 In Situ Physical/Chemical Treatment
>>4.9 Solidification/Stabilization

Introduction>> 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).

Description:

Figure 4-9a:
Typical Auger/Caisson and Reagent/Injector Head Systems

Figure 4-9b:
Typical In Situ Vitrification System Solidification/stabilization (S/S) reduces the mobility of hazardous substances and contaminants in the environment through both physical and chemical means. Unlike other remedial technologies, S/S seeks to trap or immobilize contaminants within their "host" medium (i.e., the soil, sand, and/or building materials that contain them) instead of removing them through chemical or physical treatment. Leachability testing is typically performed to measure the immobilization of contaminants. S/S techniques can be used alone or combined with other treatment and disposal methods to yield a product or material suitable for land disposal or, in other cases, that can be applied to beneficial use. These techniques have been used as both final and interim remedial measures.

Auger/caisson systems and injector head systems are techniques used in soil S/S. They apply S/S agents to soils to trap or immobilize contaminants.

Bottom barriers are horizontal subsurface barriers that prevent vertical migration by providing a floor of impermeable material beneath the waste. The installation of a grout injection bottom barrier involves directional drilling with forced grout injection. Implementation of this technology is highly dependent on the physical properties of soil.

➢ *In Situ Vitrification (ISV)*

In situ vitrification (ISV) is another in situ S/S process which uses an electric current to melt soil or other earthen materials at extremely high temperatures (1,600 to 2,000 °C or 2,900 to 3,650 °F) and thereby immobilize most inorganics and destroy organic pollutants by pyrolysis. Inorganic pollutants are incorporated within the vitrified glass and crystalline mass. Water vapor and organic pyrolysis combustion products are captured in a hood, which draws the contaminants into an off-gas treatment system that removes particulates and other pollutants from the gas. The vitrification product is a chemically stable, leach-resistant, glass and crystalline material similar to obsidian or basalt rock. The process destroys and/or removes organic materials. Radionuclides and heavy metals are retained within the molten soil.

The timeframe for in situ S/S is short- to medium-term, while in situ ISV process is typically short-term.

TOP

Synonyms:

In Situ Vitrification

DSERTS Codes:

M13 (Vitrification).
N11 (Solidification/Stabilization)

TOP

Applicability:

The target contaminant group for in situ S/S is generally inorganics (including radionuclides).

The Auger/Caisson and Reagent/Injector Head Systems have limited effectiveness against SVOCs and pesticides and no expected effectiveness against VOCs; however, systems designed to be more effective in treating organics are being developed and tested.

The ISV process can destroy or remove organics and immobilize most inorganics in contaminated soils, sludge, or other earthen materials. The process has been tested on a broad range of VOCs and SVOCs, other organics including dioxins and PCBs, and on most priority pollutant metals and radionuclides.

TOP

Limitations:

Factors that may limit the applicability and effectiveness of the in situ S/S include:

- Depth of contaminants may limit some types of application processes.
- Future usage of the site may "weather" the materials and affect ability to maintain immobilization of contaminants.
- Some processes result in a significant increase in volume (up to double the original volume).
- Certain wastes are incompatible with variations of this process. Treatability studies are generally required.
- 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 treatments.
- The solidified material may hinder future site use.
- Processing of contamination below the water table may require dewatering.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Data needs include particle size, Atterberg limits, moisture content, metal concentrations, sulfate content, organic content, density, permeability, unconfined compressive strength, leachability, pH, and microstructure analysis. For ISV, a minimum alkali content in soil (sodium and potassium oxides) of 1.4 wt% is necessary to form glass. The composition of most soils is well within the range of processability.

TOP

Performance Data:

Auger/Caisson and Reagent/Injector Head Systems processes are well demonstrated, can be applied to the most common site and waste types, require conventional materials handling equipment, and are available competitively from a number of vendors. Most reagents and additives are also widely available and relatively inexpensive industrial commodities.

Auger/Caisson and Reagent/Injector Head Systems processes have demonstrated the capability to reduce the mobility of contaminated waste by greater than 95%. The effects, over the long term, of weathering (e.g., freeze-thaw cycles, acid precipitation, and wind erosion), ground water infiltration, and physical disturbance associated with uncontrolled future land use can significantly affect the integrity of the stabilized mass and contaminant mobility in ways that cannot be predicted by laboratory tests.

There have been few, if any, commercial applications of ISV. The ISV process has been operated for test and demonstration purposes at the pilot scale and at full scale at the following sites: (1) Geosafe Corporation's test site, (2) DOE's Hanford Nuclear Reservation, (3) DOE's Oak Ridge National Laboratory, and (4) DOE's Idaho National Engineering Laboratory. More than 170 tests at various scales have been performed on a broad range of waste types in soils and sludge. A demonstration will take place at the Parsons/ETM site in Grand Ledge, Michigan, where the process is currently operating.

Process depths up to 6 meters (19 ft) have been achieved in relatively homogeneous soils. The achievable depth is limited under certain heterogeneous conditions.

TOP

Cost:

Costs for Auger/Caisson and Reagent/Injector Head Systems processes vary widely according to materials or reagents used, their availability, project size, and chemical nature of contaminants (e.g., types and concentration levels for shallow applications). The in situ soil mixing/auger techniques average $50 to $80 per cubic meter ($40 to $60 per cubic yard) for the shallow applications and $190 to $330 per cubic meter ($150 to $250 per cubic yard) for the deeper applications.

The shallow soil mixing technique processes 36 to 72 metric tons (40 to 80 tons) per hour on average, and the deep soil 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 availability of suitable reagents. Auger/Caisson and Reagent/Injector Head Systems processes require that potentially large volumes of bulk reagents and additives be transported to project sites. Transportation costs can dominate project economics and can quickly become uneconomical in cases where local or regional material sources are unavailable.

The cost for grout injection varies depending on site-specific conditions. Costs for drilling can range from $50 to $150/ft and grouting from $50 to $75/ft, not including mobilization, wash disposal, or adverse site condition expenses.

For ISV, average costs for treatability tests (all types) are $25K plus analytical fees; for PCBs and dioxins, the cost is $30K plus analytical. Equipment mobilization and demobilization costs are $200K to $300K combined. Vitrification operation cost varies with electricity costs, quantity of water, and depth of process. One recent study on the west coast estimated vitrification costs at $375-425 per ton of soil treated; while another study in the midwest estimated vitrification costs at $267 per cubic yard.

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EPA, 1989. *SITE Program Demonstration Test International Waste Technologies In Situ Stabilization/Solidification Hialeah, Florida*, Technology Evaluation Report, EPA RREL, Cincinnati, OH, EPA/540/5-89/004a.

EPA, 1989. *Soliditech, Inc. Solidification*, EPA RREL, series includes Technology Evaluation, Vol. I, EPA/540/5-89/005a; Technology Evaluation, Vol. II, EPA/540/5-89/005b, 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.

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EPA, 1994. *In-Situ Vitrification Geosafe Corporation, EPA RREL*, Demonstration Bulletin, EPA/540/MR-94/520.

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TOP

Site Information:

- EPA *SITE* Demo: Hialeah, FL
- EPA Demo: Geosafe Test Site, WA; Hanford Nuclear Reservation, WA
- DOE Demo: Hanford Reservation, WA
- EPA Demo: Douglassville, PA
- Parsons Chemical/ETM Enterprises Superfund Site, Grand Ledge, MI (interim report)
- Parsons Chemical/ETM Enterprises Superfund Site, Grand Ledge, MI (final report)
- Hanford Site, Richland, WA; Oak Ridge National Lab WAG 7
- Additional site information on the FRTR web site

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering In Situ Physical/Chemical Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

TOP

Hazard Analysis

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.3 In Situ Thermal Treatment
>>4.10 Thermal Treatment

Introduction>> Steam/hot air injection or electrical resistance/electromagnetic/fiber optic/radio frequency heating is used to increase the volatilization rate of semi-volatiles and facilitate extraction.

Description:

Figure 4-10a: Typical Six-Phase Soil Heating System.

Figure 4-10b: Typical Hot Air Injection System Thermally enhanced SVE is a full-scale technology that uses electrical resistance/electromagnetic/fiber optic/radio frequency heating or hot-air/steam injection to increase the volatilization rate of semi-volatiles and facilitate extraction. The process is otherwise similar to standard SVE (Treatment Technology Profile 4.7), but requires heat resistant extraction wells.

Thermally enhanced SVE is normally a short- to medium-term technology.

➢ *Electrical Resistance Heating*

Electrical resistance heating uses an electrical current to heat less permeable soils such as clays and fine-grained sediments so that water and contaminants trapped in these relatively conductive regions are vaporized and ready for vacuum extraction. Electrodes are placed directly into the less permeable soil matrix and activated so that electrical current passes through the soil, creating a resistance which then heats the soil. The heat dries out the soil causing it to fracture. These fractures make the soil more permeable allowing the use of SVE to remove the contaminants. The heat created by electrical resistance heating also forces trapped liquids to vaporize and move to the steam zone for removal by SVE. Six-phase soil heating (SPSH) is a typical electrical resistance heating which uses low-frequency electricity delivered to six electrodes in a circular array to heat soils. With SPSH, the temperature of the soil and contaminant is increased, thereby increasing the contaminant's vapor pressure and its removal rate. SPSH also creates an in situ source of steam to strip contaminants from soil. At this time SPSH is in the demonstration phase, and all large scale in situ projects utilize three-phase soil heating.

➢ *Radio Frequency/Electromagnetic Heating*

Radio frequency heating (RFH) is an in situ process that uses electromagnetic energy to heat soil and enhance soil vapor extraction (SVE). RFH technique heats a discrete volume of soil using rows of vertical electrodes embedded in soil (or other media). Heated soil volumes are bounded by two rows of ground electrodes with energy applied to a third row midway between the ground rows. The three rows act as a buried triplate capacitor. When energy is applied to the electrode array, heating begins at the top center and proceeds vertically downward and laterally outward through the soil volume. The technique can heat soils to over 300 °C.

RFH enhances SVE in four ways: (1) contaminant vapor pressure and diffusivity are increased by heating, (2) the soil permeability is increased by drying, (3) an increase in the volatility of the contaminant from in situ steam stripping by the water vapor; and, (4) a decrease in the viscosity

which improves mobility. The technology is self limiting; as the soil heats and dries, current will stop flowing. Extracted vapor can then be treated by a variety of existing technologies, such as granular activated carbon or incineration.

➢ *Hot Air/Steam Injection*

Hot air or steam is injected below the contaminated zone to heat up contaminated soil. The heating enhances the release of contaminants form soil matrix. Some VOCs and SVOCs are stripped from contaminated zone and brought to the surface through soil vapor extraction.

TOP

Synonyms:

DSERTS Code: M14 (Thermally Enhanced Soil Vapor Extraction).

TOP

Applicability:

High moisture content is a limitation of standard SVE that thermally enhancement may help overcome. Heating, especially radio frequency heating and electrical resistance heating can improve air flow in high moisture soils by evaporating water. The system is designed to treat SVOCs but will consequently treat VOCs. Thermally enhanced SVE technologies also are effective in treating some pesticides and fuels, depending on the temperatures achieved by the system. After application of this process, subsurface conditions are excellent for biodegradation of residual contaminants.

TOP

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 temperature achieved in the process selected.
- Soil that is tight or has high moisture content has a reduced permeability to air, hindering the operation of thermally enhanced SVE and requiring more energy input to increase vacuum and temperature.
- Soil with highly variable permeabilities may result in uneven delivery of gas flow to the contaminated regions.
- Soil that has a high organic content has a high sorption capacity of VOCs, which results in reduced removal rates.
- Air emissions may need to be regulated to eliminate possible harm to the public and the environment. Air 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 aquifer can expose more media to SVE (this may address concerns regarding LNAPLs).
- Hot air injection has limitations due to low heat capacity of air.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Data requirements include the depth and areal extent of contamination, the concentration of the contaminants, depth to water table, and soil type and properties (e.g., structure, texture, permeability, and moisture content).

TOP

Performance Data:

The thermally enhanced SVE processes are notably different and should be investigated individually for more detailed information. Because thermally enhanced SVE is an in situ remedy and all contaminants are under a vacuum during operation, the possibility of contaminant release is greatly reduced.

As with SVE, remediation projects using thermally enhanced SVE systems are highly dependent upon the specific soil and chemical properties of the contaminated media. The typical site consisting of 18,200 metric tons (20,000 tons) of contaminated media would require approximately 9 months.

DOE has developed and tested several thermally enhanced SVE processes. Dynamic underground stripping integrates steam injection and direct electric heating. Six phase soil heating is a pilot-scale technology that delivers six separate electric phases through electrodes placed in a circle around a soil vent. Thermally enhanced vapor extraction system combines conventional SVE with both powerline frequency and radio frequency soil heating.

TOP

Cost:

The key cost driver information and cost analysis was developed using the 2006 version of the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Soil Type
  - The primary cost driver is soil type, which once again determines soil permeability. For thermal treatment, soils of lower permeability (silts/silty-clays) are less expensive to remediate as they require less gas flow.
- Depth to Top/Thickness of Contaminated Area
  - The secondary cost drivers are depth to the top and thickness of the contaminated zone. A deeper and thicker region of contaminated soils has higher remedial costs.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply thermal treatment technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Thermal Treatment			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
CUBIC YARDS PROCESSED	5,550	5,550	16,650	16,650
COST PER CUBIC YARD	$51	$62	$29	$38
COST PER 1000 CUBIC YARDS	$50,947	$61,502	$29,174	$37,634

Detailed Cost Estimate

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Remediation Technology Cost Compendium - Year 2000

Groundwater Cleanup: Overview of Operating Experience at 28 Sites, September 1999, EPA 542-R-99-006,

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Federal Remediation Technologies Roundtable, 1997. *Remediation Case Studies: Soil Vapor Extraction and Other In Situ Technologies*, EPA/542/R-97/009.

- In Situ Enhanced Soil Mixing at the U.S. Department of Energy's Portsmouth Gaseous Diffusion Plant, X-231B Unit, Piketon, Ohio
- Six Phase Soil Heating at the U.S. Department of Energy's Savannah River Site, M Area, Aiken, South Carolina; and Hanford Site, 300-Area, Richland, Washington

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

Ramirez, A.L and W.D. Daily, 1995. *Monitoring Six-Phase Ohmic Heating of Contaminated Soils Using Electrical Resistance Tomography*, UCRL-ID-118418, Lawrence Livermore National Laboratory, Livermore, CA.

WESTON, IIT Research Institute, November 1992. *Final Rocky Mountain Arsenal In Situ Radio Frequency Heating/Vapor Extraction Pilot Test Report, Vol. I*, U.S. Army Report 5300-01-12-AAFP.

TOP

Site Information:

- DOE Demo: LLNL, CA
- Air Force Demo: Volk Field ANGB, WI
- DOE Demo: Hanford Reservation, WA
- DOE Demo: Sandia National Laboratory, NM
- EPA Demo: Annex Terminal, San Pedro, CA
- EPA Demo: LeMoore NAS, CA
- EPA Demo: San Fernando Valley Ground Water Basin Superfund Site, CA
- EPA Demo: Huntington Beach, CA
- EPA Demo: Pennsylvania Power and Light, PA
- Air Force & EPA Demo: Kelly AFB, TX
- Lockheed Aeronautical Systems Burbank, CA
- Kelly AFB, TX
- U.S. DOE's Savannah River Site, M Area, Aiken, SC
- DOE's Portsmouth Gaseous Diffusion Plant, X-231B Unit, Piketon, OH
- Additional Site Information on the FRTR Web Site

Points of Contact:

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A list of vendors offering In Situ Thermal Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

Hazard Analysis

TOP

Technology>> Soil, Sediment, Bedrock, and Sludge
>>3.4 Ex Situ Biological Treatment (assuming excavation)
>>4.11 Biopiles

Introduction>> Excavated soils are mixed with soil amendments and placed in aboveground enclosures. It is an aerated static pile composting process in which compost is formed into piles and aerated with blowers or vacuum pumps.

Description:

Figure 4-11: Typical Biopile for Solid Phase Bioremediation Biopile treatment is a full-scale technology in which excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration. It is used to reduce concentrations of petroleum constituents in excavated soils through the use of biodegradation. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.

The treatment area will generally be covered or contained with an impermeable liner to minimize the risk of contaminants leaching into uncontaminated soil. The drainage itself may be treated in a bioreactor before recycling. Vendors have developed proprietary nutrient and additive formulations and methods for incorporating the formulation into the soil to stimulate biodegradation. The formulations are usually modified for site-specific conditions.

Soil piles and cells commonly have an air distribution system buried under the soil to pass air through the soil either by vacuum or by positive pressure. The soil piles in this case can be up to 20 feet high (generally not recommended, 2-3 meters maximum). Soil piles may be covered with plastic to control runoff, evaporation, and volatilization and to promote solar heating. If there are VOCs in the soil that will volatilize into the air stream, the air leaving the soil may be treated to remove or destroy the VOCs before they are discharged to the atmosphere.

Biopile is a short-term technology. Duration of operation and maintenance may last a few weeks to several months. Treatment alternatives include static processes such as: prepared treatment beds, biotreatment cells, soil piles, and composting.

TOP

Synonyms:

Heap pile bioremediation; Bioheaps; Biomounds; Static-pile composting.
DSERTS Code: H14 (Controlled Solid-Phase Bioremediation).

TOP

Applicability:

Biopile treatment has been applied to treatment of nonhalogenated VOCs and fuel hydrocarbons. Halogenated VOCs, SVOCs, and pesticides also can be treated, but the process effectiveness will vary and may be applicable only to some compounds within these contaminant groups.

Limitations:

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

- Excavation of contaminated soils is required.
- Treatability testing should be conducted to determine the biodegradability of contaminants and appropriate oxygenation and nutrient loading rates.
- Solid phase processes have questionable effectiveness for halogenated compounds and may not be very effective in degrading transformation products of explosives.
- Similar batch sizes require more time to complete cleanup than slurry phase processes.
- Static treatment processes may result in less uniform treatment than processes that involve periodic mixing.

TOP

Data Needs:

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

- 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 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 degradation byproducts.
- Percent reduction and lower concentration limit of contaminant achievable.
- The potential degradation rate.

TOP

Performance Data:

Biopile treatment has been demonstrated for fuel-contaminated sites. Specific site information is contained in the following site information Section.

TOP

Cost:

Costs are dependent on the contaminant, procedure to be used, need for additional pre- and post-treatment, and need for air emission control equipment. Biopiles are relatively simple and require few personnel for operation and maintenance. Typical costs with a prepared bed and liner are $130 to $260 per cubic meter ($30 to $60 per cubic yard).

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Remediation Technology Cost Compendium - Year 2000

Potential Applicability of Assembled Chemical Weapons Assessment Technologies to RCRA Waste Streams and Contaminated Media, August 2000, EPA 542-R-00-004

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

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Sims, J.L., et al., 1989. *Bioremediation of Contaminated Surface Soils*, EPA, RSKERL, Ada, OK, EPA Report EPA/600/9-89/073.

von Fahnestock, F.M., et al., 1996. *Biopile Design and Construction Manual*, Navel Facilities Engineering Service Center Technical Memorandum, Port Hueneme, CA, TM-2189-ENV.

TOP

Site Information:

- Marine Corps Air Ground Combat Center
- Mobil Terminal Buffalo, NY
- Matagorda Island AF Range, TX
- Navy Marine Corps Mountain Warfare Center Bridgeport, CA
- NEL Demo: NAS North Island Bioremediation Treatment Facility (BTF), CA
- Additional site information on the FRTR web site

Points of Contact:

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Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

TOP

A list of vendors offering Ex Situ Biological Soil Treatment is available from EPA REACH IT which

combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

TOP

Hazard Analysis

TOP

Technology>> Soil, Sediment, Bedrock, and Sludge
>>3.4 Ex Situ Biological Treatment (assuming excavation)
>>4.12 Composting

Introduction>> Contaminated soil is excavated and mixed with bulking agents and organic amendments such as wood chips, hay, manure, and vegetative (e.g., potato) wastes. Proper amendment selection ensure adequate porosity and provides a balance of carbon and nitrogen to promote thermophilic, microbial activity.

Description:

Figure 4-12: Typical Windrow Composting Process Composting is a controlled biological process by which organic contaminants (e.g., PAHs) are converted by microorganisms (under aerobic and anaerobic conditions) to innocuous, stabilized byproducts. Typically, thermophilic conditions (54 to 65 °C) must be maintained to properly compost soil contaminated with hazardous organic contaminants. The increased temperatures result from heat produced by microorganisms during the degradation of the organic material in the waste. In most cases, this is achieved by the use of indigenous microorganisms. Soils are excavated and mixed with bulking agents and organic amendments, such as wood chips, animal, and vegetative wastes, to enhance the porosity of the mixture to be decomposed. Maximum degradation efficiency is achieved through maintaining oxygenation (e.g., daily windrow turning), irrigation as necessary, and closely monitoring moisture content, and temperature.

There are three process designs used in composting: aerated static pile composting (compost is formed into piles and aerated with blowers or vacuum pumps), mechanically agitated in-vessel composting (compost is placed in a reactor vessel where it is mixed and aerated), and windrow composting (compost is placed in long piles known as windrows and periodically mixed with mobile equipment). Windrow composting is usually considered to be the most cost-effective composting alternative. Meanwhile, it may also have the highest fugitive emissions. If VOC or SVOC contaminants are present in soils, off-gas control may be required.

TOP

Synonyms:

Solid-phase soil treatment, Ex situ treatment.
DSERTS Code: H16 (Composting).

TOP

Applicability:

The composting process may be applied to soils and lagoon sediments contaminated with biodegradable organic compounds. Pilot and full-scale projects have demonstrated that aerobic, thermophilic composting is able to reduce the concentration of explosives (TNT, RDX, and HMX), ammonium picrate (or yellow-D), and associated toxicity to acceptable levels. Aerobic, thermophilic composting is also applicable to PAH-contaminated soil. All materials and equipment used for composting are commercially available.

TOP

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 VOCs.
- Composting results in a volumetric increase in material because of the addition of amendment material.
- Although levels of metals may be reduced via dilution, heavy metals are not treated by this method. Also high levels of heavy metals can be toxic to the microorganisms.

TOP

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 compost process include contaminant concentration, excavation requirements, availability and cost of amendments required for compost mixture, space available for treatment, soil type, and amenability of the contaminants to composting.

TOP

Performance Data:

Windrow composting has been demonstrated as an effective technology for treatment of explosives-contaminated soil. During a field demonstration conducted by USAEC and the Umatilla Depot Activity (UMDA), TNT reductions were as high as 99.7% in 40 days of operation, with the majority of removal occurring in the first 20 days of operation. Maximum removal efficiencies for RDX and HMX were 99.8% and 96.8%, respectively. The relatively simple equipment requirements combined with these performance results make windrow composting economically and technically attractive.

TOP

Cost:

Costs will vary with the amount of soil to be treated, the soil fraction in the compost, availability of amendments, the type of contaminant, and the type of process design employed. This composting analysis estimates the cost of composting contaminated soils using windrows. The cost of providing a treatment pad with leachate collection is included. The key cost driver information and cost analysis was developed using the 2006 version of the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Contaminant
    - Contaminant type is the primary cost driver for composting.
- Soil type/total organic content (TOC)
    - Soils of higher density (in general, fine-grained sands and gravels) have lower composting costs, while soils of higher TOC have higher composting costs. The density influences the mass of soil to be treated, while the percent TOC indicates the level of contamination.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply composting technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs

can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Composting			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
CUBIC YARDS PROCESSED	13,000	13,000	24,000	24,000
COMPOSTING COST PER CUBIC YARD	$259	$345	$249	$321
TOTAL COST PER CUBIC YARD	$489	$578	$481	$555
COST PER 1000 CUBIC YARDS	$488,988	$577,588	$480,682	$554,982

Detailed Cost Estimate

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Remediation Technology Cost Compendium - Year 2000

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- Windrow Composting to Treat Explosives-contaminated Soil at Umatilla Army Depot Activity, Hermiston, Oregon (Full-scale Remediation)
- Composting at the Dubose Oil Products Co. Superfund Site, Cantonment, Florida

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Williams, R.T., P.S. Ziegenfuss, and P.J. Marks, September 1988. *Field Demonstration - Composting of Explosives-Contaminated Sediments at the Louisiana Army Ammunition Plant*, USATHAMA Report AMXTH-IR-TE-88242.

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Williams, R.T. and P.J. Marks, November 1991. *Optimization of Composting for Explosives-Contaminated Soils*, USATHAMA Report CETHA-TS-CR-91053.

TOP

Site Information:

- UMDA Hermiston, OR (Field Demo)
- LAAP Shreveport, LA
- Cliff/Dow Disposal Site Marquet
- Army Demo: Louisiana Army Ammunition Plant, LA
- Army Demo: Badger Army Ammunition Plant, WI
- Army Demo: Umatilla Depot Activity, OR
- Dubose Oil Products Co. Superfund, FL
- UMDA Hermiston, OR (Full Scale)
- Additional site information on the FRTR web site

Points of Contact:

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Non Government Web Sites

Vendor Information:

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A list of vendors offering Ex Situ Biological Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their

applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.4 Ex Situ Biological Treatment (assuming excavation)
>>4.13 Landfarming

Introduction>> Contaminated soil, sediment, or sludge is excavated, applied into lined beds, and periodically turned over or tilled to aerate the waste.

Description:

Figure 4-13a: Typical Landfarming Treatment Unit

Landfarming is a full-scale bioremediation technology, which usually incorporates liners and other methods to control leaching of contaminants, which requires excavation and placement of contaminated soils, sediments, or sludges. Contaminated media is applied into lined beds and periodically turned over or tilled to aerate the waste.

Soil conditions are often controlled to optimize the rate of contaminant degradation. Conditions normally controlled include:

- Moisture content (usually by irrigation or spraying).
- Aeration (by tilling the soil with a predetermined frequency, the soil is mixed and aerated).
- pH (buffered near neutral pH by adding crushed limestone or agricultural lime).
- Other amendments (e.g., Soil bulking agents, nutrients, etc.).

Contaminated media is usually treated in lifts that are up to 18 inches thick. When the desired level of treatment is achieved, the lift is removed and a new lift is constructed. It may be desirable to only remove the top of the remediated lift, then construct the new lift by adding more contaminated media to the remaining material and mixing. This serves to inoculate the freshly added material with an actively degrading microbial culture, and can reduce treatment times.

Figure 4-13b:
Typical Land Treatment Unit

Land Treatment is a full-scale bioremediation technology in which contaminated soils, sediments, or sludges are turned over (i.e., tilled) and allowed to interact with the soil and climate at the site. The waste, soil, climate, and biological activity interact dynamically as a system to degrade, transform, and immobilize waste constitutes. Wastes are periodically tilled to aerate the waste.

Soil conditions are often controlled to optimize the rate of contaminant degradation. Conditions normally controlled include:

- Moisture content (usually by irrigation or spraying).
- Aeration (by tilling the soil with a predetermined frequency, the soil is mixed and aerated).
- pH (buffered near neutral pH by adding crushed limestone or agricultural lime).
- Other amendments (e.g., Soil bulking agents, nutrients, etc.).

A Land Treatment site must be managed properly to prevent both on-site and off-site problems with ground water, surface water, air, or food chain contamination. Adequate monitoring and

environmental safeguards are required.

Landfarming and Land Treatment are both medium- to long-term technologies.

TOP

Synonyms:

Solid phase biodegradation.
DSERTS Code: H15 (Landfarming).

TOP

Applicability:

Ex situ landfarming 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 extraction), 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 using landfarming 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.

TOP

Limitations:

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

- A large amount of space is required.
- Conditions affecting biological degradation of contaminants (e.g., temperature, rain fall) are largely uncontrolled, which increases the length of time to complete remediation.
- Inorganic contaminants will not be biodegraded.
- Volatile contaminants, such as solvents, must be pretreated because they would volatilize into the atmosphere, causing air pollution.
- Dust control is an important consideration, especially during tilling and other material handling operations.
- Runoff collection facilities must be constructed and monitored.
- Topography, erosion, climate, soil stratigraphy, and permeability of the soil at the site must be evaluated to determine the optimum design of facility.
- Waste constitutes may be subject to "Land-ban" regulation and thus may not be applied to soil for treatment by landfarming (e.g., some petroleum sludges).

TOP

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).

TOP

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.

TOP

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; and less than $100,000 for pilot tests or field demonstrations.
- Cost of prepared bed (ex situ treatment and placement of soil on a prepared liner): Under $100 per cubic meter (under $75 per cubic yard).

TOP

References:

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Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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Groundwater Cleanup: Overview of Operating Experience at 28 Sites, September 1999, EPA 542-R-99-006,

Potential Applicability of Assembled Chemical Weapons Assessment Technologies to RCRA Waste Streams and Contaminated Media, August 2000, EPA 542-R-00-004

Treatment Experiences at RCRA Corrective Actions, December 2000, EPA 542-F-00-020

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

Seminars: Bioremediation of Hazardous Waste Sites: Practical Approaches to Implementation, Environmental Protection Agency (EPA), May 1996, Land Treatment, pages 6-1 through 6-16; and

Remediation Handbook for POL-Contaminated Sites, Headquarters United States Air Force Environmental Restoration Program, December 1993, Section 4.4, Treatment of Excavated Soil.

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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.

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Site Information:

- EPA Remedial Action: Brown Wood Preserving, FL
- EPA Removal Action: Poly-Carb, Inc., NV
- EPA Removal Action: Scott Lumber, MO
- Lowry AFB, CO
- Army Ft. Ord Marina, Fritzche AAF Fire Drill Area, CA
- Navy Demo: Camp Pendleton, CA
- Petroleum Products Terminal
- Fuel Oil Spill
- Creosote
- Pesticide Storage Facility
- Additional site information on the FRTR web site

Points of Contact:

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Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge >>3.4 Ex Situ Biological Treatment (assuming excavation) >>4.14 Slurry Phase Biological Treatment

Introduction>> An aqueous slurry is created by combining soil, sediment, 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.

Description:

Figure 4-14:
Typical Bioreactor Process

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 concentration 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, a slurry contains from 10 to 30% solids by weight.

The solids are 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.

Slurry-phase bioreactors may be classified as short- to medium-term technologies.

TOP

Synonyms:

Slurry biodegradation.
DSERTS Code: H13 (Slurry-Phase Bioremediation).

TOP

Applicability:

Bioremediation techniques have been successfully used to remediate soils, sludges, and sediments contaminated by explosives, petroleum hydrocarbons, petrochemicals, solvents, pesticides, wood preservatives, and other organic chemicals. Bioreactors are favored over in situ biological techniques for heterogenous soils, low permeability soils, areas where underlying ground water would be difficult to capture, or when faster treatment times are required.

Slurry-phase bioreactors are used primarily to treat nonhalogenated SVOCs and VOCs in excavated soils or dredged sediments. Ordnance compounds may also be treated.

Slurry-phase bioreactors containing cometabolites and specially adapted microorganisms are both used to treat halogenated VOCs and SVOCs, pesticides, and PCBs in excavated soils and dredged sediments.

Sequential anaerobic/aerobic slurry-phase bioreactors are used to treat PCBs, halogenated SVOCs, pesticides, and ordnance compounds found in excavated soils or dredged sediments.

TOP

Limitations:

Factors that may limit the applicability and effectiveness of the slurry-phase biotreatment process include:

- Excavation of contaminated media is required, except for lagoon implementation.
- Sizing of materials prior to putting them into the reactor can be difficult and expensive. Nonhomogeneous soils and clayey soils can create serious materials handling problems. In the case of free phase contaminant, precluded removal is mandatory.
- Dewatering soil fines after treatment can be expensive.
- An acceptable method for disposing of nonrecycled wastewaters is required.

TOP

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. A preliminary treatability study should be conducted.

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.

TOP

Performance Data:

Aerobic bioslurry was used to reduce TNT, HMX, and RDX concentration in soil at Joliet Army Ammunition Plant, IL. Slurry phase bioremediation demonstrated a removal rate over 99% and a high degree of mineralization. Studies in support of a feasibility study at Iowa Army Ammunition Plant developed designs and cost estimates for full scale application of aerobic and anaerobic bioslurry processes. Demonstrations of three different bioslurry processes are underway: the Simplot Anaerobic bioremediation (SABRE) process, the Anoxic/Aerobic bioslurry process developed by AEC in conjunction with Argonne National Lab, and a 'generic' anaerobic bioslurry process.

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.

TOP

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.

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

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- Slurry-phase Bioremediation at the French Limited Superfund Site, Crosby, Texas

Federal Remediation Technologies Roundtable, 1997. *Remediation Case Studies: Bioremediation and Vitrification*, EPA/542/R-97/008.

- Slurry-phase Bioremediation at the Southeastern Wood Preserving Superfund Site, Canton, Mississippi

Montamagno, C.D., 1990. *Feasibility of Biodegrading TNT-Contaminated Soils in a Slurry Reactor - Final Technical Report*, USATHAMA Report CETHA-TE-CR-90062.

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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.

TOP

Site Information:

- Former Manufac. Gas Plant (MGP) Site, NJ
- Iowa Army Ammunition Plant, Middletown, IA
- Army Demo: Joliet Army Ammunition Plant, IL
- Navy Demo: Naval Weapons Station unleaded gasoline spill, Seal Beach, CA
- EPA *SITE* Demo: EPA Test & Evaluation Facility, OH
- EPA *SITE* Demo
- French Limited Superfund Site, Crosby, TX
- Southeastern Wood Preserving Superfund Site, Canton, MS
- Additional site information on the FRTR web site

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Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.5 Ex Situ Physical/Chemical Treatment (assuming excavation)
>>4.15 Chemical Extraction

Introduction>> Waste contaminated soil and extractant are mixed in an extractor, thereby dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.

Description:

Figure 4-15
Typical Chemical Extraction Process

Chemical 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 extracting chemical 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 chemical employed, type of equipment used, and mode of operation.

Physical separation steps are often used before chemical extraction to grade the soil into coarse and fine fractions, with the assumption that the fines contain most of the contamination. Physical separation can also enhance the kinetics of extraction by separating out particulate heavy metals, if these are present in the soil.

➢ *Acid Extraction*

Acid can also be used as the extractant. Acid extraction uses hydrochloric acid to extract heavy metal contaminants from soils. In this process, soils are first screened to remove coarse solids. Hydrochloric acid is then introduced into the soil in the extraction unit. The residence time in the unit varies depending on the soil type, contaminants, and contaminant concentrations, but generally ranges between 10 and 40 minutes. The soil-extractant mixture is continuously pumped out of the mixing tank, and the soil and extractant are separated using hydrocyclones.

When extraction is complete, the solids are transferred to the rinse system. The soils are rinsed with water to remove entrained acid and metals. The extraction solution and rinse waters are regenerated using comercially available precipitants, such as sodium hydroxide, lime, or other proprietary formulations, along with a flocculent that removes the metals and reforms the acid. The heavy metals are concentrated in a form potentially suitable for recovery. During the final step, the soils are dewatered and mixed with lime and fertilizer to neutralize any residual acid.

➢ *Solvent Extraction*

Solvent extraction is a common form of chemical extraction using organic solvent as the extractant. It is commonly used in combination with other technologies, such as solidification/stabilization, incineration, or soil washing, depending upon site-specific conditions. Solvent extraction also can be used as a stand alone 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.

The duration of operations and maintenance for chemical extraction is medium-term.

TOP

Synonyms:

DSERTS Codes:

N16 (Acid Extraction)
N17 (Solvent Extraction)

TOP

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 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.

Acid extraction is suitable to treat sediments, sludges, and soils contaminated by heavy metals.

TOP

Limitations:

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

- Some soil types and moisture content levels will adversely impact process performance.
- Higher clay content may reduce extraction efficiency and require longer contact times.
- 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.
- After acid extraction, any residual acid in treated soil needs to be neutralized.
- Capital costs can be relatively high and the technology may be more economical at larger sites.
- Meeting highly stringent heavy metals criteria (e.g., passing the California WET test) may prove uneconomical.

TOP

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.

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Economy of Scale
  - Quantity of material treated has a large impact
- Moisture content in waste
  - Slight increase in costs between soil and sludge

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply chemical extraction technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Chemical Extraction			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER CUBIC FOOT	$45	$49	$10	$10
COST PER CUBIC METER	$1,582	$1,717	$358	$361
COST PER CUBIC YARD	$1,202	$1,305	$272	$275

Detailed Cost Estimate

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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Potential Applicability of Assembled Chemical Weapons Assessment Technologies to RCRA Waste Streams and Contaminated Media, August 2000, EPA 542-R-00-004

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- Solvent Extraction at the Sparrevohn Long Range Radar Station, Alaska

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.

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Site Information:

- EPA Removal Action: Traband Warehouse PCBs, OK
- EPA Removal Action: Stanford Pesticide Site No. 1, AZ
- EPA Remedial Action: Palmetto Wood Preserving, SC

- EPA Removal Action: PBM Enterprises, MI
- EPA Removal Action: Zhiegner Refining Company
- EPA Demo: Midwest, California, Australia
- EPA Demo: Grand Calumet River Site, IL
- EPA SITE Demo: Research Facility, Edison, NJ
- United Creosoting, Conroe, TX
- DOE pilot-scale test, Idaho National Engineering Laboratory
- SUPERFUND Remedial Action, Arrowhead Refinery Co.
- EPA SITE Demo: Naval Air Station North Island Site 4, San Diego, CA
- EPA Removal Action: General Refining Company, GA
- EPA Removal Action: Vineland Chemical Company, NJ
- EPA Removal Action: Avtex Fibers, VA
- EPA & Navy Demo: EPA Lab, NJ
- EPA Demo: Douglassville, PA
- EPA Demo
- Star Enterprise, Port Arthur, TX
- EPA Demo: New Bedford Harbor, MA & O'Connor Site, ME
- Sparrevohn Long Range Radar Station, AK
- Additional site information on the FRTR web site

Points of Contact:

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Technology Specific Web Sites:

Non Government Web Sites

Vendor Information:

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A list of vendors offering Ex Situ Physical/Chemical Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.5 Ex Situ Physical/Chemical Treatment (assuming excavation)
>>4.16 Chemical Reduction/Oxidation

Introduction>> 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.

Description:

Figure 4-16
Typical Chemical Reduction/Oxidation Process

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 reduction/oxidation is a short- to medium-term technology.

TOP

Synonyms:

DSERTS Code: N13 (Chemical Reduction/Oxidation).

TOP

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.

TOP

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.

TOP

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:

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 (oxidation) and chromium (reduction of Cr (VI) to Cr (III) prior to precipitation) wastes. Enhanced systems are now being used more frequently to treat hazardous wastes in soils.

TOP

Cost:

Estimated costs range from $190 to $660 per cubic meter ($150 to $500 per cubic yard).

Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes (HTRW) Historical Cost Analysis System (HCAS) developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group.

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References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Potential Applicability of Assembled Chemical Weapons Assessment Technologies to RCRA Waste Streams and Contaminated Media, August 2000, EPA 542-R-00-004

Treatment Experiences at RCRA Corrective Actions, December 2000, EPA 542-F-00-020

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

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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.

USAEC, 1997. "Catalyzed Hydrogen Peroxide Treatment of 2, 4, 6-Trinitrotoluene in Soils" in *Innovative Technology Demonstration, Evaluation and Transfer Activities, FY 96 Annual Report,* Report No. SFIM-AEC-ET-CR-97013, pp. 77-78.

USAEC, 1997. "Remediation of Chemical Agent Contaminated Soils Using Peroxysulfate" in *Innovative Technology Demonstration, Evaluation and Transfer Activities, FY 96 Annual Report,* Report No. SFIM-AEC-ET-CR-97013, pp. 93-94.

TOP

Site Information:

- EPA Demo: Coleman-Evans Site, FL
- Additional site information on the FRTR web site

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Site:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering Ex Situ Physical/Chemical Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.5 Ex Situ Physical/Chemical Treatment (assuming excavation)
>>4.17 Dehalogenation

Introduction>> Reagents are added to soils contaminated with halogenated organics. The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.

Description:

Figure 4-17a:
Typical BCD Dehalogenation Process

Figure 4-17b:
Typical APEG Dehalogenation Process

Contaminated soil is screened, processed with a crusher and pug mill, and mixed with reagents. The mixture is heated in a reactor. The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.

➢ *Base-catalyzed Decomposition (BCD)*

Base-catalyzed decomposition (BCD) process was developed by EPA's Risk Reduction Engineering Laboratory (RREL), in cooperation with the Naval 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 reactor to partially decompose and volatilize the contaminants. The volatilized contaminants are captured, condensed, and treated separately.

➢ *Glycolate/Alkaline Polyethylene Glycol (APEG)*

Glycolate is a full-scale technology in which an alkaline polyethylene glycol (APEG) reagent is used. 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. 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. Dehalogenation (APEG/KPEG) is generally considered a stand alone 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.

Dehalogenation is normally a short- to medium-term process. The contaminant is partially decomposed rather than being transferred to another medium.

TOP

Synonyms:

DSERTS Code: N14 (Dehalogenation).

TOP

Applicability:

The target contaminant groups for dehalogenation treatment are halogenated SVOCs and pesticides. APEG dehalogenation is one of the few processes available other than incineration that has been successfully field tested in treating PCBs.The technology can be used but may be less effective against selected halogenated VOCs. The technology is amenable to small-scale applications. The BCD can be also used to treat halogenated VOCs but will generally be more expensive than other alternative technologies.

TOP

Limitations:

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

- High clay and moisture content will increase treatment costs.
- The APEG/KPEG technology is generally not cost-effective for large waste volumes.
- Concentrations of chlorinated organics greater than 5% require large volumes of reagent.
- With the BCD process, capture and treatment of residuals (volatilized contaminants captured, dust, and other condensates) may be difficult, especially when the soil contains high levels of fines and moisture.

TOP

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.

TOP

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.

Glycolate process 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.

TOP

Cost:

The cost for full-scale operation is estimated to be in a range of $220 to $550 per metric ton ($200 to $500 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.

Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes (HTRW) Historical Cost Analysis System (HCAS) developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group.

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References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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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. *Reductive Dehalogenation of Organic Contaminants in Soils and Ground Water*, EPA/540/4-90/054.

EPA, 1990. *Treating Chlorinated Wastes with the KPEG Process*, Project Summary, EPA RREL, Cincinnati, OH, EPA/600/S2-90/026.

EPA, 1991. *BCD: An EPA-Patented Process for Detoxifying Chlorinated Wastes*, EPA, ORD.

EPA, 1992. *A Citizen's Guide to Glycolate Dehalogenation*, EPA, OSWER, Washington, DC, EPA/542/F-92/005.

EPA, 1996. *A Citizen's Guide to Chemical Dehalogenation*, EPA/542/F-96/004.

Federal Remediation Technologies Roundtable, 1995. *Remediation Case Studies: Thermal Desorption, Soil Washing, and In Situ Vitrification*, EPA/542/R-95/005.

- Thermal Desorption/Dehalogenation at the Wide Beach Development Superfund Site, Brant, New York

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.

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.

TOP

Site Information:

- EPA Remedial Action: Wide Beach Development, NY
- PWC Guam
- Montana Pole Butte, MT
- Economy Products Omaha, NE
- EPA Removal Action: Signo Trading International, Inc., NY

Points of Contact:

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Government Disclaimer

Health and Safety:

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.5 Ex Situ Physical/Chemical Treatment
>>4.18 Separation

Introduction>> Separation techniques concentrate contaminated solids through physical and chemical means. These processes seek to detach contaminants from their medium (i.e., the soil, sand, and/or binding material that contains them).

Description:

Figure 4-18: Typical Gravity Separation System

The separation processes are used for removing contaminated concentrates from soils, to leave relatively uncontaminated fractions that can then be regarded as treated soil. Ex situ separation can be performed by many processes. Gravity separation and sieving/physical separation are two well-developed processes that have long been primary methods for treating municipal wastewaters. Magnetic separation, on the other hand, is a much newer separation process that is still being tested.

➢ *Gravity Separation*

Gravity separation is a solid/liquid separation process, which relies on a density difference between the phases. Equipment size and effectiveness of gravity separation depends on the solids settling velocity, which is a function of the particles size, density difference, fluid viscosity, and particle concentration (hindered settling). Gravity separation is also used for removing immiscible oil phases, and for classification where particles of different sizes are separated. It is often preceded by coagulation and flocculation to increase particle size, thereby allowing removal of fine particles.

➢ *Magnetic Separation*

Magnetic separation is used to extract slightly magnetic radioactive particles from host materials such as water, soil, or air. All uranium and plutonium compounds are slightly magnetic while most host materials are nonmagnetic. The process operates by passing contaminated fluid or slurry through a magnetized volume. The magnetized volume contains a magnetic matrix material such as steel wool that extracts the slightly magnetic contamination particles from the slurry.

➢ *Sieving/Physical Separation*

Sieving and physical separation processes use different size sieves and screens to effectively concentrate contaminants into smaller volumes. Physical separation is based on the fact that most organic and inorganic contaminants tend to bind, either chemically or physically, to the fine (i.e., clay and silt) fraction of a soil. The clay and silt soil particles are, in turn, physically bound to the coarser sand and gravel particles by compaction and adhesion. Thus, separating the fine clay and silt particles from the coarser sand and gravel soil particles would effectively concentrate the contaminants into a smaller volume of soil that could then be further treated or disposed.

TOP

Synonyms:

NA

TOP

Applicability:

The target contaminant groups for ex situ separation processes are SVOCs, fuels, and inorganics (including radionuclides). The technologies can be used on selected VOCs and pesticides. Magnetic separation is specifically used on heavy metals, radionuclides, and magnetic radioactive particles, such as uranium and plutonium compounds.

Physical separation often precedes chemical extraction treatment based on the assumption that most of the contamination is tied to the finer soil fraction, which alone may need to be treated. Separation is also useful when heavy metal contaminants occur as particulates (e.g., in small-arms ranges). One advantage of physical separation processes is that high throughputs can be achieved with relatively small equipment.

TOP

Limitations:

Factors that may limit the applicability and effectiveness of these processes include:

- High clay and moisture content will increase treatment cost.
- Gravity separation processes rely on a difference in the solids and liquid phase densities. Specific gravity of particles will effect settling rate and process efficiency. Additionally, settling velocity is dependent on the viscosity of the suspending fluid, which must be known to estimate process efficiency and to size equipment.
- Special measures may be required to mitigate odor problems, resulting from organic sludge that undergoes septic conditions.

TOP

Data Needs:

A detailed discussion of data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). In addition, particle size distribution; soil type, physical form, handling properties, and moisture content; contaminant type and concentration; texture; and organic content need to be investigated.

TOP

Performance Data:

Gravity separation and sieving/physical separation are full-scale, well-established technologies used mostly for treatment of wastewater and contaminated soil, sediment, and sludge. Magnetic separation is a promising new technique used to remove radioactive contaminants from soils. It has recently been tested at the bench-scale level at DOE sites.

TOP

Cost:

NA

Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes (HTRW) Historical Cost Analysis System (HCAS) developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group.

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References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

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Battelle Memorial Institute, 1995. *ReOpt. V3.1,* by Battelle Memorial Institute for DOE under Contract DE/AC06/76RLO 1830.

Coyne Prenger, 1995. *High Gradient Magnetic Separation (HGMS),* Los Alamos National Laboratory (LANL), LALP-94-264.

DOE, April 1995. *Technology Catalogue, Second Edition,* Office of Environmental Management & Office of Technology Development, DOE/EM-0235.

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Site Information:

- Los Alamos National Laboratory (LANL)
- DOE Demo: INEL, ID
- EPA Demo: Iron Mountain Mine Site, CA
- Twin Cities AAP, New Brighton, MN
- Additional site information on the FRTR web site

Points of Contact:

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Government Disclaimer

Health and Safety:

Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.5 Ex Situ Physical/Chemical Treatment (assuming excavation)
>>4.19 Soil Washing

Introduction>> 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.

Description:

Figure 4-19: Typical Soil Washing Process Ex situ soil separation processes (often referred to as "soil washing"), mostly based on mineral processing techniques, are widely used in Northern Europe and America for the treatment of contaminated soil. Soil washing is a water-based process for scrubbing soils ex situ to remove contaminants. The process removes contaminants from soils in one of the followingtwo ways:

- By dissolving or suspending them in the wash solution (which can be sustained by chemical manipulation of pH for a period of time); or
- 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.

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. However, attrition washing can increase the fines in soils processed. The clean, larger fraction can be returned to the site for continued use.

Complex mixture of contaminants in the soil (such as a mixture of metals, nonvolatile organics, and SVOCs) and heterogeneous contaminant compositions throughout the soil mixture make it difficult to formulate a single suitable washing solution that will consistently and reliably remove all of the different types of contaminants. for these cases, sequential washing, using different wash formulations and/or different soil to wash fluid ratios, may be required.

Soil washing is generally considered a media transfer technology. The contaminated water generated from soil washing are treated with the technology(s) suitable for the contaminants.

The duration of soil washing is typically short- to medium-term.

TOP

Synonyms:

DSERTS Code: N15 (Soil Washing).

TOP

Applicability:

The target contaminant groups for soil washing are SVOCs, fuels, and heavy metals. The technology can be used on selected VOCs and pesticides. The technology offers the ability for recovery of metals and can clean a wide range of organic and inorganic contaminants from coarse-grained soils.

TOP

Limitations:

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

- 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 at demobilization.
- Additional treatment steps may be required to address hazardous levels of washing solvent remaining in the treated residuals.
- It may be difficult to remove organics adsorbed onto clay-size particles.

TOP

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. A complete bench scale treatability study should always be completed before applying this technology as a remedial solution.

TOP

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 provides a cost effective and environmentally proactive alternative to stabilization and landfilling. Two pilot scale demonstrations were carried out at Fort Polk, Louisiana in 1996. These employed commercially available unit processes - physical separation/acid leaching systems. The system employed acetic acid as the leaching agent, and the other, hydrochloric acid. Input soil had a lead content of approximately 3500 mg/kg. The hydrochloric acid system was most effective. Processed soil had total lead concentration of 200 mg/kg and TCLP levels for lead of approximately 2 mg/L. The through put rate was approximately 6 tons per hour. Choice of acid leaching agent is a function of specific soil chemistry and degree of solubility required.

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Economy of Scale
    - Quantity of material treated has a large impact
- Processor speed
    - Also depends on the amount of waste being processed

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply soil washing technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Soil Washing	
RACER PARAMETERS	Scenario A **Small Site**	Scenario B **Large Site**
COST PER CUBIC FOOT	**$5**	**$2**
COST PER CUBIC METER	**$187**	**$70**
COST PER CUBIC YARD	**$142**	**$53**

Detailed Cost Estimate

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References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

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BDM, 1997. *Demonstration of Physical Separation/Leaching Methods for the Remediation of Heavy Metals-Contaminated Soils at Small-Arms Range Final Report.* Prepared for U.S. Army Environmental Center (USAEC) and Naval Facilities Engineering Service Center under contract with

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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.

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EPA, 1997. *Best Management Practices (BMPs) for Soil Treatment Technologies: Suggested Operational Guidelines to Prevent Cross-media Transfer of Contaminants During Clean-UP Activities*, EPA OSWER, EPA/530/R-97/007.

Federal Remediation Technologies Roundtable, 1995. *Remediation Case Studies: Thermal Desorption, Soil Washing, and In Situ Vitrification*, EPA/542/R-95/005.

- Soil Washing at the King of Prussia Technical Corporation Superfund Site, Winslow Township, New Jersey

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.

TOP

Site Information:

- Ft. Polk, LA
- Twin Cities AAP, New Brighton, MN
- EPA Demo: Santa Maria, CA
- Army Saginaw Bay Confined Disposal Facility, MI
- DOE Demo: Clemson Technical Center, SC
- EPA & DOE Demo: Montclair, West Orange & Glen Ridge Sites, NJ
- EPA Demo: Toronto Port Industrial District, Canada

- Army Demo: Sacramento Army Depot, CA
- DOE Demo: Fernald Site, OH
- EPA Demo: Alaska Battery Enterprises Superfund Site, AK
- EPA Demo: MacGillis & Gibbs Superfund Site, MN
- EPA Demo: Pensacola, FL
- Toronto Port Industrial Dist., Ontario, Canada
- Escambia Wood Treating Company Superfund Site, Pensacola, FL
- NEL Demo: NAS North Island Installation Restoration (IR) Site 4
- King of Prussia Technical Corporation Superfund Site, Winslow Township, NJ
- Additional site information on the FRTR web site

Points of Contact:

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Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering Ex Situ Physical/Chemical Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

TOP

Hazard Analysis

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.5 Ex Situ Physical/Chemical Treatment (assuming excavation)
>>4.20 Solidification/Stabilization

Introduction>> 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).

Description:

Figure 4-20: Typical Ex Situ Solidification/ stabilization Process Flow Diagram

As for in situ solidification/stabilization (S/S) (see Technology Profile No. 4.9), 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. Under CERCLA, material can be replaced on site.

There are many innovations in the stabilization and solidification technology. Most of the innovations are modifications of proven processes and are directed to encapsulation or immobilizing the harmful constituents and involve processing of the waste or contaminated soil. Nine distinct innovative processes or groups of processes include: (1) bituminization, (2) emulsified asphalt, (3) modified sulfur cement, (4) polyethylene extrusion, (5) pozzolan/Portland cement, (6) radioactive waste solidification, (7) sludge stabilization, (8)soluble phosphates, and (9) vitrification/molten glass.

Typical ex situ S/S is a short- to medium-term technology.

➢ *Bituminization*

In the bituminization process, wastes are embedded in molten bitumen and encapsulated when the bitumen cools. The process combines heated bitumen and a concentrate of the waste material, usually in slurry form, in a heated extruder containing screws that mix the bitumen and waste. Water is evaporated from the mixture to about 0.5% moisture. The final product is a homogenous mixture of extruded solids and bitumen.

➢ *Emulsified Asphalt*

Asphalt emulsions are very fine droplets of asphalt dispersed in water that are stabilized by chemical emulsifying agents. The emulsions are available as either cationic or anionic emulsions. The emulsified asphalt process involves adding emulsified asphalts having the appropriate charge to hydrophilic liquid or semiliquid wastes at ambient temperature. After mixing, the emulsion breaks, the water in the waste is released, and the organic phase forms a continuous matrix of hydrophobic asphalt around the waste solids. In some cases, additional neutralizing agents, such as lime or gypsum, may be required. After given sufficient time to set and cure, the resulting solid asphalt has the waste uniformly distributed throughout it and is impermeable to water.

➢ *Modified Sulfur Cement*

Modified sulfur cement is a commercially-available thermoplastic material. It is easily melted (127° to 149° C (260° to 300° F)) and then mixed with the waste to form a homogenous molten slurry which is discharged to suitable containers for cooling, storage, and disposal. A variety of common mixing devices, such as, paddle mixers and pug mills, can be used. The relatively low temperatures used limit emissions of sulfur dioxide and hydrogen sulfide to allowable threshold values.

➢ *Polyethylene Extrusion*

The polyethylene extrusion process involves the mixing of polyethylene binders and dry waste materials using a heated cylinder containing a mixing/transport screw. The heated, homogenous mixture exits the cylinder through an output die into a mold, where it cools and solidifies. Polyethylene's properties produce a very stable, solidified product. The process has been tested on nitrate salt wastes at plant-scale, thereby establishing its viability, and on various other wastes at the bench and pilot scale.

➢ *Pozzolan/Portland Cement*

Pozzolan/Portland cement process consists primarily of silicates from pozzolanic-based materials like fly ash, kiln dust, pumice, or blast furnace slag and cement-based materials like Portland cement. These materials chemically react with water to form a solid cementious matrix which improves the handling and physical characteristics of the waste. They also raise the pH of the water which may help precipatate and immobilize some heavy metal contaminants. Pozzolanic and cement-based binding agents are typically appropriate for inorganic contaminants. The effectiveness of this binding agent with organic contaminants varies.

➢ *Radioactive Waste Solidification*

In radioactive waste solidification (Grouting/Other) treatment, solidification additives are used to form a uniform and stable matrix to encapsulate radioactive waste materials. Assemblies include pumps for liquids or slurries, conveyors for sludges or solids, storage silos, weigh feeders, piping, mixers and disposal or storage.

➢ *Sludge Stabilization*

The sludge stabilization process is the addition of a reagent, either slags or cementitious materials, to sludge to transform the material so that the hazardous constituents are in their least mobile or toxic form. Sludges which leach heavy metals or other contaminants are often stabilized to immobilize the hazardous constituents.

➢ *Soluble Phosphates*

The soluble phosphates process involves the addition of various forms of phosphate and alkali for control of pH as well as for formation of complex metal molecules of low-solubility to immobilize (insolubilize) the metals over a wide pH range. Unlike most other stabilization processes, soluble phosphate processes do not convert the waste into a hardened, monolithic mass. One application of soluble phosphates and lime is in stabilizing fly ash by immobilizing the lead and cadmium in the ash.

➢ *Vitrification/Molten Glass*

Vitrification, or molten glass, processes are solidification methods that employ heat up to 1,200° C to melt and convert waste materials into glass or other glass and crystalline products. The high temperatures destroy any organic constituents with very few byproducts. Materials, such as heavy metals and radionuclides, are actually incorporated into the glass structure which is, generally, a relatively strong, durable material that is resistant to leaching. In addition to solids, the waste materials can be liquids, wet or dry sludges, or combustible materials. Borosilicate and soda-lime are the principal glass formers and provide the basic matrix of the vitrified product.

TOP

Synonyms:

DSERTS Code:

M13 (Vitrification)
N11 (Solidification/Stabilization)

TOP

Applicability:

The target contaminant group for ex situ S/S is inorganics, including radionuclides. Most S/S technologies have limited effectiveness against organics and pesticides, except vitrification which destroys most organic contaminants.

TOP

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.
- Organics are generally not immobilized.
- Long-term effectiveness has not been demonstrated for many contaminant/process combinations.

TOP

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.

TOP

Performance Data:

The performance of ex situ S/S is dependent on the type of S/S process used.

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). Scale-up from bench-scale tests has demonstrated the feasibility to process waste at approximately 2,000 lb/hr. The scale-up feasibility tests have successfully demonstrated the potential to encapsulate at least 60% by weight nitrate salt in polyethylene. Polyethylene waste forms have been demonstrated to exceed Nuclear Regulatory Commission, EPA, and Department of Transportation waste form criteria. Waste forms containing up to several thousand ppm of toxic-metal contaminants have passed the EPA's TCLP.

DOE also demonstrated the arc melter vitrification process, which is capable of melting soil and metals, pyrolizing or oxidizing residual organics, melting structural metals from melted slag (silica and metal oxides), and partitioning transuranic (TRU) waste into slag phase. Durability tests with the resultant slag showed an approximately order of magnitude reduction in leachability when compared with high-level borosilicate glass.

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Type of Waste
  - Moisture content in the sludge drives up costs compared to solid
  - Contaminant concentration and type determine the amount of reagents added to the waste to attain the required treatment standards
- Size of the mobile s/s system
  - Choosing the correct size mobile s/s system to adequately handle the throughput of waste volume

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply solidification/stabilization technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Solidification/Stabilization			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER CUBIC FOOT	$6	$7	$4	$5
COST PER CUBIC METER	$216	$248	$124	$190
COST PER CUBIC YARD	$165	$189	$94	$144

Detailed Cost Estimate

TOP

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Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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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.

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EPA, 1997. *Best Management Practices (BMPs) for Soil Treatment Technologies: Suggested Operational Guidelines to Prevent Cross-media Transfer of Contaminants During Clean-UP Activities*, EPA OSWER, EPA/530/R-97/007.

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Federal Remediation Technologies Roundtable, 1997. *Remediation Case Studies: Soil Vapor Extraction and Other In Situ Technologies*, EPA/542/R-97/009.

- In Situ Enhanced Soil Mixing at the U.S. Department of Energy's Portsmouth Gaseous Diffusion Plant, X-231B Unit, Piketon, Ohio

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Debris and Surface Cleaning Technologies, and Other Miscellaneous Technologies*, EPA/542/R-98/017.

- Polyethylene Macroencapsulation at Envirocare of Utah, Inc., Salt Lake City, Utah

USAEC, 1997. "Plasma Arc Technology Evaluation" in *Innovative Technology Demonstration, Evaluation and Transfer Activities, FY 96 Annual Report,* Report No. SFIM-AEC-ET-CR-97013, pp. 107-110.

Wittle, J.K., et.al., 1995. *Graphite Electrode DC Arc Technology Program for Buried Waste Treatment*, Electro-Pyrolysis, Inc. Wayne, Penn.

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Site Information:

- EPA *SITE* Demo: Robins AFB, Macon, GA
- EPA *SITE* Demo: Selma Pressure Treating Selma, CA
- EPA *SITE* Demo: Portable Equip. Salvage Co. Clackamas, OR
- Navy Demo: Naval Const. Battalion Ctr. Port Hueneme, CA
- Imperial Oil Co./Champion Chemical Co. Superfund Site Morganville, NJ
- Small Arms Range, Naval Air Station Mayport, FL
- Davis-Monthan AFB
- DOI Demo: Salt Lake City Research Center
- DOI Demo: Albany Metallurgy Research Center, OR
- EPA & DOE Demo: Component Development & Integration Facility, MT
- NEL Demo: NAS North Island Installation Restoration (IR) Site 11, CA
- Envirocare of Utah, Inc., Salt Lake City, Utah
- DOE's Portsmouth Gaseous Diffusion Plant, X-231B Unit, Piketon, OH
- Additional site information on the FRTR web site

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering Ex Situ Physical/Chemical Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

TOP

Hazard Analysis

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.6 Ex Situ Thermal Treatment (assuming excavation)
>>4.21 Hot Gas Decontamination

Introduction>> 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.

Description:

Figure 4-21a: Typical Process Flow Diagram
for Hot Gas Decontamination of Explosives Contaminated Equipment

Figure 4-21b: Specifics - Typical Process Flow Diagram
for Hot Gas Decontamination of Explosives Contaminated Equipment

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.

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.

TOP

Synonyms:

NA

TOP

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.

TOP

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.

TOP

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.

TOP

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.

TOP

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.

TOP

References:

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McNeill, W., et al., October 1987. *Pilot Plant Testing of Hot Gas Building Decontamination Process - Final Report*, USATHAMA Report AMXTH-TE-CR-87130.

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USAEC, 1997. "Transportable Hot Gas Decontamination" in *Innovative Technology Demonstration, Evaluation and Transfer Activities, FY 96 Annual Report*, Report No. SFIM-AEC-ET-CR-97013, pp. 115-117.

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.

TOP

Site Information:

- EPA Demo: Hamilton Harbor, Canada
- HWAAP Hawthorne, NV
- EPA Demo: Babcock & Wilcox, OH
- Additional site information on the FRTR web site

Points of Contact:

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Government Disclaimer

Health and Safety:

TOP

To be added

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.6 Ex Situ Thermal Treatment (assuming excavation)
>>4.22 Incineration

Introduction>> High temperatures, 870-1,200 °C (1,600- 2,200 °F), are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.

Description:

Figure 4-22: Typical Mobile/Transportable Incineration Process 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. Often auxiliary fuels are employed to initiate and sustain combustion. 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. Off gases and combustion residuals generally require treatment.

➢ *Circulating Bed Combustor (CBC)*

Circulating bed combustor (CBC) uses high velocity air to entrain circulating solids and create a highly turbulent combustion zone that destroys toxic hydrocarbons. The CBC operates at lower temperatures than conventional incinerators (1,450 to 1,600 °F). The CBC's high turbulence produces a uniform temperature around the combustion chamber and hot cyclone. The CBC also completely mixes the waste material during combustion. Effective mixing and low combustion temperature reduce operating costs and potential emissions of such gases as nitrogen oxide (NOx) and carbon monoxide (CO).

➢ *Fluidized Bed*

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 °F (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 °F (1,600 °F).

➢ *Infrared Combustion*

The infrared combustion technology is a mobile thermal processing system that uses electrically-powered silicon carbide rods to heat organic wastes to combustion temperatures. Waste is fed into the primary chamber and exposed to infrared radiant heat (up to 1,850 °F) provided by silicon carbide rods above the conveyor belt. A blower delivers air to selected locations along the belt to control the oxidation rate of the waste feed. Any remaining combustibles are incinerated in an afterburner.

➢ *Rotary Kilns*

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 °F (1,800 °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.

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).

The duration of incineration technology ranges from short- to long-term.

TOP

Synonyms:

DSERTS Code: D1 (Incineration).

TOP

Applicability:

Incineration is used to remediate soils contaminated with explosives and hazardous wastes, particularly chlorinated hydrocarbons, PCBs, and dioxins.

TOP

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.

TOP

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 , the soil fusion temperature, and the soil heating value. A sieve analysis is required to accurately estimate the dust loading in the system for proper design of the air pollution control equipment.

TOP

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.

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Type of waste
  - Debris < Soil < Sludge < Sediment
- Quantity
  - There is only a $300 - $400 gap in cost for quantities ranging from 5,000 – 100,000.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply incineration technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Incineration			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER CUBIC FOOT	$30	$44	$26	$40
COST PER CUBIC METER	$1,047	$1,540	$914	$1,399
COST PER CUBIC YARD	$796	$1,171	$695	$1,063

Detailed Cost Estimate

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Remediation Technology Cost Compendium - Year 2000

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EPA, 1997. *On-Site Incineration: Overview of Superfund Operating Experience.*

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: On-Site Incineration*, EPA/542/R-98/016.

- Incineration at the Baird and McGuire Superfund Site, Holbrook, Massachusetts
- Incineration at the Bayou Bonfouca Superfund Site, Slidell, Louisiana
- Incineration at the Bridgeport Refinery and Oil Services Superfund Site, Logan Township, New Jersey
- Incineration at the Celanese Superfund Site, Shelby, North Carolina
- Incineration at the Coal Creek Superfund Site, Chehalis, Washington
- Incineration at the FMC Corporation - Yakima Pit Superfund Site, Yakima, Washington
- Incineration at the Former Nebraska Ordnance Plant Site, Mead, Nebraska
- Incineration at the MOTCO Superfund Site, Texas City, Texas
- Incineration at the Old Midland Products Superfund Site, Ola, Arkansas
- Incineration at the Petro Processors Superfund Site, Baton Rouge, Louisiana
- Incineration at the Rocky Mountain Arsenal Superfund Site, Commerce City, Colorado
- Incineration at the Rose Disposal Pit Superfund Site, Lanesborough, Massachusetts
- Incineration at the Rose Township Dump Superfund Site, Holly, Michigan
- Incineration at the Sikes Disposal Pits Superfund Site, Crosby, Texas
- Incineration at the Times Beach Superfund Site, Times Beach, Missouri

- Incineration at the Vertac Chemical Corporation Superfund Site, Jacksonville, Arkansas

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TOP

Site Information:

- EPA Demo: Ogden's Research Facility San Diego, CA
- EPA *SITE* Demo: Monaca, PA
- EPA *SITE* Demos: (1) Tampa, FL, (2) Rose Township/Demode Road Superfund Site, MI
- Peak Oil Site Tampa, FL
- Savanna AD, Savanna, IL
- Lauder Salvage Yard, Beardstown, IL
- Baird and McGuire Superfund Site, Holbrook, MA
- Bayou Bonfouca Superfund Site, Slidell, LA
- Bridgeport Refinery and Oil Services Superfund Site, Logan Township, NJ
- Celanese Superfund Site, Shelby, NC
- Coal Creek Superfund Site, Chehalis, WA
- FMC Corporation - Yakima Pit Superfund Site, Yakima, WA
- Former Nebraska Ordnance Plant Site, Mead, NE
- MOTCO Superfund Site, Texas City, TX
- Old Midland Products Superfund Site, Ola, AR
- Petro Processors Superfund Site, Baton Rouge, LA
- Rocky Mountain Arsenal Superfund Site, Commerce City, CO
- Rose Disposal Pit Superfund Site, Lanesborough, MA
- Rose Township Dump Superfund Site, Holly, MI
- Sikes Disposal Pits Superfund Site, Crosby, TX
- Times Beach Superfund Site, Times Beach, MO
- Vertac Chemical Corporation Superfund Site, Jacksonville, AR
- Additional site information on the FRTR web site

Points of Contact:

TOP

General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

TOP

A list of vendors offering Ex Situ Thermal Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

TOP

Hazard Analysis

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.6 Ex Situ Thermal Treatment (assuming excavation)
>>4.23 Open Burn/Open Detonation

Introduction>> 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. In OD operations, detonatable explosives and munitions are destroyed by a detonation, which is generally initiated by the detonation of an energetic charge.

Description:

Figure 4-23: Typical Open Burning Pan and Cage Open burn (OB) and open detonation (OD) operations are conducted to destroy excess, obsolete, or unserviceable (EOU) munitions and energetic materials. In OB operations, energetics or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as flame, heat, or a detonation wave. In this case, an auxilliary fuel may be added to initiate and sustain the combustion of materials. In OD operations, detonatable explosives and munitions are destroyed by a detonation, which is generally initiated by the detonation of an energetic charge.

In the past, OB/OD generally occured in the surface of the land or in pits. Recently, burn trays and blast boxes are being used in an attempt to control and contain the destruction of energetics and resulting contaminants/emissions. In detonation processes the blast box may be below grade and covered with soil to further minimize the release of emissions.

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 energetics 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.

OB and OD can be initiated either by electric, burning, or energetic charge 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. In some cases, scrap energetics or dried activated carbon from pink/red water treatment may be used as the initiation charge.

TOP

Synonyms:

NA

TOP

Applicability:

OB/OD can be used to destroy excess, obsolete, or unserviceable (EOU) munitions, components, energetic materials, as well as, media contaminated with energetics.

TOP

Limitations:

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

- Minimum distance requirements for safety purposes mean substantial space is required for open processes.
- OB/OD operations emissions are difficult to sufficiently capture for treatment and may not be permitted in areas with emissions limitations, although subsurface processes minimize emission release.
- In open OB/OD operations, prevailing winds must 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.
- OB/OD requires a RCRA Subpart X permit.
- In addition, with growing OB/OD restriction, DOD's ability to treat energetic wastes is diminishing and energetics disposal, through OB/OD, may be eliminated.

TOP

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.

TOP

Performance Data:

Several federal agencies are pursuing new technologies in this area including:

- DOE's molten salt technology,
- U.S. Army Construction Engineering Research Laboratory's (CERL) pyrolysis of energetic materials,
- U.S. Army Research Laboratory's supercritical fluid technology for nitramine recovery,
- U.S. Army Research and Development Engineering Center's (ARDEC) single- and multi-base propellant recovery technologies,
- Naval Surface Warfare Center (NSWC) Indian Head Division's supercritical fluid propellant extraction process,
- Armstrong Laboratory's hydrothermal oxidation for propellant destruction, and
- Holston Army Amunition Plant's (AAP) recovery of waste explosives.

TOP

Cost:

Not available.

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Groundwater Cleanup: Overview of Operating Experience at 28 Sites, September 1999, EPA 542-R-99-006,

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Treatment Experiences at RCRA Corrective Actions, December 2000, EPA 542-F-00-020

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USAF, 1990. *Explosives Safety Standards*, Air Force Regulation 127-100.

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TOP

Site Information:

Not Available.

Points of Contact:

TOP

General FRTR Agency Contacts

Technology Specific Web Sites:

Non Government Web Sites

Vendor Information:

TOP

A list of vendors offering In Situ Physical/Chemical Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

TOP

Hazard Analysis

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.6 Ex Situ Thermal Treatment (assuming excavation)
>>4.24 Pyrolysis

Introduction>> 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.

Description:

Figure 4-24: Typical Pyrolysis Process 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.

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 produces 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.

Conventional thermal treatment methods, such as rotary kiln, rotary hearth furnace, or fluidized bed furnace, are used for waste pyrolysis. Kilns or furnaces used for pyrolysis would be physically similar to the equipment described in Section 4.23 "Incineration", but would operate at lower temperature and with less air supply than would be required for combustion. Molten salt process may also be used for waste pyrolysis. These processes are described in the following sections:

➢ *Rotary Kiln* .

The rotary kiln is a refractory-lined, slightly-inclined, rotating cylinder that serves as a heating chamber.

➢ *Fluidized Bed Furnace*

The circulating fluidized bed uses high-velocity air to circulate and suspend the waste particles in a heating loop and operates at temperatures up to 430 °C (800 °F).

➢ *Molten Salt Destruction*

Molten-salt destruction is another type of pyrolysis. In molten-salt destruction, a molten salt incinerator uses a molten, turbulent bed of salt, such as sodium carbonate, as a heat transfer and reaction/scrubbing meduim to destroy hazardous materials. Shredded solid waste is injected with air under the surface of the molten salt. Hot gases composed primarily of carbon dioxide, stream, and

unreacted air components rise through the molten salt bath, pass throught a secondary reaction zone, and through an off gas cleanup system before discharging to the atmosphere. Other pyrolysis by-products react with the alkaline molten salt to form inorganic products that are retained in the melt. Spent molten salt containing ash is tapped from the reactor, cooled and placed in a landfill.

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.

TOP

Synonyms:

Molten solid processing; Plasma pyrolysis.

TOP

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.

TOP

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.

TOP

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), and the soil fusion temperature.

TOP

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.

TOP

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).

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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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.

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Shah, J.K., T.J. Schultz, and V.R. Daiga, 1989. "Pyrolysis Processes." Section 8.7 in *Standard Handbook of Hazardous Waste Treatment and Disposal*, ed. H.M. Freeman. McGraw-Hill Book Company, New York, NY.

TOP

Site Information:

- DOE Demo: Energy Technology Engineering Center, ORNL, LANL
- HT-V TDI Thermal Dynamics
- Deutsche Babcock Anlagen AG
- Wide Beach Superfund Site NY SoilTech, Inc.
- Additional site information on the FRTR web site

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering En Situ Thermal Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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To be added

TOP

Technology>> Soil, Sediment, Bedrock and Sludge
>>3.6 Ex Situ Thermal Treatment (assuming excavation)
>>4.25 Thermal Desorption

Introduction>> Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.

Description:

Figure 4-25a: Typical High Temperature Thermal Desorption Process
Figure 4-25b: Typical Low Temperature Thermal Desorption Process

Thermal desorption is a physical separation process and is not designed to destroy organics. Wastes are heated 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.

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.

Three types of thermal desorption are available and briefly described as following:

1. Direct Fired: Fire is applied directly upon the surface of contaminated media. The main purpose of the fire is to desorb contaminants from the soil though some contaminants may be thermally oxidized.
2. Indirect Fired: A direct-fired rotary dryer heats an air stream which, by direct contact, desorbs water and organic contaminants from the soil. The Low Temperature Thermal Aeration (LTTA®) developed by Canonie Environmental Services Corporation is a good example of indirect fired system which has been successfully used to remove DDT family compounds from soil.
3. Indirect Heated: An externally fired rotary dryer volatilizes the water and organics from the contaminated media into an inert carrier gas stream. The carrier gas is later treated to remove or recover the contaminants. XTRAX™ thermal Desorption System is a process using indirect heated desorption followed by a high-energy scrubber gas treatment, which successfully removed >99% of PCB from contaminated soil.

Based on the operating temperature of the desorber, thermal desorption processes can be categorized into two groups: high temperature thermal desorption (HTTD) and low temperature thermal desorption (LTTD).

➢ *High Temperature Thermal Desorption (HTTD)*

HTTD is a full-scale technology in which wastes are heated to 320 to 560 °C (600 to 1,000 °F). 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.

➢ *Low Temperature Thermal Desorption (LTTD)*

In LTTD, wastes are heated to between 90 and 320 °C (200 to 600 °F). 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. Unless being heated to the higher end of the LTTD temperature range, organic components in the soil are not damaged, which enables treated soil to retain the ability to support future biological activity.

TOP

Synonyms:

DSERTS Code: N12 (Thermal Desorption). Low Temperature Thermal Desorption (LTTD).

TOP

Applicability:

Thermal desorption systems have varying degrees of effectiveness against the full spectrum of organic contaminants.

The target contaminant groups for LTTD systems are nonhalogenated VOCs and fuels. The technology can be used to treat SVOCs at reduced effectiveness.

The target contaminants for HTTD are SVOCs, PAHs, PCBs, and pesticides; however, 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 waste, pesticides and paint wastes.

TOP

Limitations:

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

- There are specific particle 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.
- Clay and silty soils and high humic content soils increase reaction time as a result of binding of contaminants.

TOP

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, 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. A sieve analysis is needed to determine the dust loading in the system to properly design and size the air pollution control equipment.

TOP

Performance Data:

Most of the hardware components for thermal desorption systems are readily available off the shelf. 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.

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.

The time to complete cleanup of the "standard" 18,200-metric ton (20,000-ton) site using HTTD is just over 4 months.

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 increase the throughput of the desorber and to facilitate the conveying of the feed to the desorber. Some volatilization of contaminants occurs in the dryer, and the gases are routed to a thermal treatment chamber.

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Economy of Scale
  - Quantity of material treated has a large impact
- Moisture content
  - Increases required heat input (increasing fuel costs)

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply thermal desorption technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

SOIL TECHNOLOGY:	Thermal Desorption

RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER CUBIC FOOT	$2	$7	$1	$3
COST PER CUBIC METER	$81	$252	$44	$110
COST PER CUBIC YARD	$75	$232	$40	$101

Detailed Cost Estimate

TOP

References:

A Citizen's Guide to Thermal Desorption (English Version) 2001.

A Process Description of Terra Therm's Thermal Desorption Process.

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

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Federal Remediation Technologies Roundtable, 1995. *Remediation Case Studies: Thermal Desorption, Soil Washing, and In Situ Vitrification*, EPA/542/R-95/005.

- Thermal Desorption at the Anderson Development Company Superfund Site, Adrian, Michigan
- Thermal Desorption at the McKin Company Superfund Site, Gray, Maine
- Thermal Desorption at the Pristine, Inc. Superfund Site, Reading, Ohio (Complete Cost and Performance Report,PDF Version)
- Thermal Desorption at the T H Agriculture & Nutrition Company Superfund Site, Albany, Georgia
- Thermal Desorption/Dehalogenation at the Wide Beach Development Superfund Site, Brant, New York

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Ex Situ Soil Treatment Technologies (Bioremediation, Solvent Extraction, Thermal Desorption)*, EPA/542/R-98/011

- Vacuum-enhanced, Low Temperature Thermal Desorption at the FCX Washington Superfund Site, Washington, North Carolina
- Thermal Desorption at the Solvent Refined Coal Pilot Plant, Fort Lewis, Washington
- Thermal Desorption at Naval Air Station Cecil Field, Site 17, OU 2, Jacksonville, Florida
- Thermal Desorption at the Outboard Marine Corporation Superfund Site, Waukegan, Illinois
- Thermal Desorption at the Port Moller Radio Relay Station, Port Moller, Alaska
- Thermal Desorption at the Re-Solve, Inc. Superfund Site, North Dartmouth, Massachusetts
- Thermal Desorption at the Waldick Aerospace Devices Superfund Site, Wall Township, New Jersey

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- In Situ Thermal Desorption at the Missouri Electric Works Superfund Site, Cape Girardeau, Missouri

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.

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Site Information:

- EPA Remedial Action: McKin, ME
- EPA Remedial Action: Otteti & Goss, NH
- EPA Remedial Action: Outboard Marina, Waukegan Harbor (OU 3), IL
- EPA Remedial Action: Cannon Engineering/ MA
- EPA Removal Action: Drexler RAMCOR, WA
- EPA Demo: ReSolve, Inc., Superfund Site, MA
- EPA Demo: Wide Beach Development Superfund Site, NY & Outboard Marine Corp., IL
- EPA Demo: Niagara-Mohawk Power Co., NY
- EPA Demo: Pesticide Site, AZ
- Army Demo: Letterkenny Army Depot, PA
- EPA & Army Demo: Tinker AFB, OK & Anderson Development Co. Superfund Site, MI
- EPA *SITE* Demo: EPA Combustion Research Facility, Jefferson, AK
- Alaskan Battery Enterprises Superfund Site, Fairbanks, AK
- Escambia Wood Treating Company, Superfund Site, Pensacola, FL
- Pristine, Inc., Reading, OH
- T H Agriculture & Nutrition Company Superfund Site, Albany, GA
- Anderson Development Company Superfund Site, Adrian, MI
- McKin Company Superfund Site, Gray, ME
- Port Moller Radio Relay Station, Port Moller, AK
- FCX Washington Superfund Site, Washington, NC
- The Solvent Refined Coal Pilot Plant, Fort Lewis, WA
- Naval Air Station Cecil Field, Site 17, OU 2, Jacksonville, FL
- Outboard Marine Corporation Superfund Site, Waukegan, IL
- The Re-Solve, Inc. Superfund Site, North Dartmouth, MA
- Waldick Aerospace Devices Superfund Site, Wall Township, NJ
- Missouri Electric Works Superfund Site, Cape Girardeau, MO
- Additional site information on the FRTR web site

Points of Contact:

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A list of vendors offering Ex Situ Thermal Soil Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.7 Containment
>>4.26 Landfill Cap

Introduction>> Landfill caps are used for contaminant source control.

Description:

Figure 4-26: Typical RCRA Subtitle C Landfill Cap System Landfill caps can be used to:

- Minimize exposure on the surface of the waste facility.
- Prevent vertical infiltration of water into wastes that would create contaminated leachate.
- Contain waste while treatment is being applied.
- Control gas emissions from underlying waste.
- Create a land surface that can support vegetation and/or be used for other purposes.

Landfill Capping is the most common form of remediation because it is generally less expensive than other technologies and effectively manages the human and ecological risks associated with a remediation site.

The design of landfill caps is site specific and depends on the intended functions of the system. Landfill Caps can range from a one-layer system of vegetated soil to a complex multi-layer system of soils and geosynthetics. In general, less complex systems are required in dry climates and more complex systems are required in wet climates. The material used in the construction of landfill caps include low-permeability and high-permeability soils and low-permeability geosynthetic products. The low-permeability materials divert water and prevent its passage into the waste. The high permeability materials carry water away that percolates into the cap. Other materials may be used to increase slope stability.

The most critical components of a landfill cap are the barrier layer and the drainage layer. The barrier layer can be low-permeability soil (clay) and/or geosynthetic clay liners (GCLs). A flexible geomembrane liner is placed on top of the barrier layer. Geomembranes are usually supplied in large rolls and are available in several thickness (20 to 140 mil), widths (15 to 100 ft), and lengths (180 to 840 ft). The candidate list of polymers commonly used is lengthy, which includes polyvinyl chloride (PVC), polyethylenes of various densities, reinforced chlorosulfonated polyethylene (CSPE-R), polypropylene, ethylene interpolymer alloy (EIA), and many newcomers. Soils used as barrier materials generally are clays that are compacted to a hydraulic conductivity no greater than 1×10^{-6} cm/sec. Compacted soil barriers are generally installed in 6-inch minimum lifts to achieve a thickness of 2 feet or more. A composite barrier uses both soil and a geomembrane, taking advantage of the properties of each. The geomembrane is essentially impermeable, but, if it develops a leak, the soil component prevents significant leakage into the underlying waste.

For facilities on top of putrescible wastes, the collection and control of methane and carbon dioxide, potent greenhouse gases, must be part of facility design and operation.

➢ *Asphalt/Concrete Cap*

The most effective single-layer caps are composed of concrete or bituminous asphalt. It is used to form a surface barrier between landfill and the environment. An asphalt concrete cap would reduce leaching through the landfill into an adjacent aquifer.

➢ *RCRA Subtitle C Cap*

The RCRA C multilayered landfill cap is a baseline design that is suggested for use in RCRA hazardous waste applications. These caps generally consist of an upper vegetative (topsoil) layer, a drainage layer, and a low permeability layer which consists of a synthetic liner over 2 feet of compacted clay. The compacted clay liners are effective if they retain a certain moisture content but are susceptible to cracking if the clay material is desiccated. As a result alternate cap designs are usually considered for arid environments.

➢ *RCRA Subtitle D Cap*

RCRA Subtitle D requirements are for non-hazardous waste landfills. The design of a landfill cover for a RCRA Subtitle D facility is generally a function of the bottom liner system or natural subsoils present. The cover must meet the following specifications:

- the material must have a permeability no greater than 1 x 10-5 cm/s, or equivalent permeability of any bottom liner or natural subsoils present, whichever is less.
- The infiltration layer must contain at least 45 cm of earthen material.
- The erosion control layer must be at least 15 cm of earthen material capable of sustaining native plant growth.

Alternative design can be considered, but must be of equivalent performance as the specifications outlined above. All covers should be designed to prevent the "bathtub" effect. The bathtub effect occurs when a more permeable cover is placed over a less permeable bottom liner or natural subsoil. The landfill then fills up like a bathtub.

TOP

Synonyms:

Cap; Landfill cover; Surface cover.
DSERTS Codes:

I0 (Containment)
I1 (Capping)

TOP

Applicability:

Landfill Caps may be temporary or final. Temporary caps can be installed before final closure to minimize generation of leachate until a better remedy is selected. They are usually used to minimize infiltration when the underlying waste mass is undergoing settling. A more stable base will thus be provided for the final cover, reducing the cost of the post-closure maintenance. Landfill caps also may be applied to waste masses that are so large that other treatment is impractical. At mining sites for example, caps can be used to minimize the infiltration of water to contaminated tailings piles and to provide a suitable base for the establishment of vegetation. In conjunction with water diversion and detention structures, landfill caps may be designed to route surface water away from the waste area while minimizing erosion.

TOP

Limitations:

Landfilling does not lessen toxicity, mobility, or volume of hazardous wastes, but does mitigate migration. Landfill caps are most effective where most of the underlying waste is above the water table. A cap, by itself, cannot prevent the horizontal flow of ground water through the waste, only the vertical entry of water into the waste. In many cases landfill caps are used in conjunction with vertical walls to minimize horizontal flow and migration. The effective life of landfill components

(including cap) can be extended by long-term inspection and maintenance. Vegetation, which has a tendency for deep root penetration, must be eliminated from the cap area. In addition, precautions must be taken to assume that the integrity of the cap is not compromised by land use activities.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge). Many laboratory tests are needed to ensure that the materials being considered for each of the landfill cap components are suitable. Tests to determine the suitability of soil include grain size analysis, Atterberg limits, and compaction characteristics. Landfill instability can be solved by understanding interface friction properties between all material layers, natural or synthetic. The major engineering soil properties that must be defined are the shear strength and hydraulic conductivity. Shear strength may be determined with the unconfined compression test, direct shear test, or triaxial compression test. Hydraulic conductivity of soils may be measured in the laboratory by the constant head permeability test or the falling head permeability test. Field hydraulic conductivity tests on test pads are generally recommended prior to actual cover construction to ensure that the low-permeability requirements can actually be met under construction conditions.

Laboratory tests are also needed to ensure that geosynthetic materials will meet the cap requirements, For example, geosynthetics in caps may be subjected to tensile stresses caused by subsidence and by the gravitational tendency of a geomembrane or material adjacent to it to slide or be pulled down slopes.

Since facility performance is a function of quality construction more so than selection of materials, construction quality assurance of caps are critical. EPA has generated a technical guidance document on this subject. The technical guidance should be strictly followed during design and construction.

TOP

Performance Data:

Previously installed caps are hard to monitor for performance. Monitoring well systems or infiltration monitoring systems can provide some information, but it is often not possible to determine whether the water or leachate originated as surface water or ground water. Performance can be monitored much more effectively by including pan lysimeter in future caps.

TOP

Cost:

Landfill caps are generally the least expensive way to manage the human health and ecological risks effectively. Rough industry cost are $175k/acre for RCRA Subtitle D, and $225k/acre for RCRA Subtitle C.

Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes (HTRW) Historical Cost Analysis System (HCAS) developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group.

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EPA, 1997. *Technology Alternatives for the Remediation of Soils Contaminated with As, Cd, Cr, Hg, and Pb*, Engineering Bulletin, EPA540/R-97/008.

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Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: In Situ Soil Treatment Technologies (Soil Vapor Extraction, Thermal Processes)*, EPA/542/R-98/012

- Soil Vapor Extraction at the Seymour Recycling Corporation Superfund Site, Seymour, Indiana

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Groundwater Pump and Treat (Nonchlorinated Solvents)*, EPA/542/R-98/014

- Pump and Treat and Containment of Contaminated Groundwater at the Sylvester/Gilson Road Superfund Site, Nashua, New Hampshire

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Debris and*

Surface Cleaning Technologies, and Other Miscellaneous Technologies, EPA/542/R-98/017.

- Lawrence Livermore National Laboratory (LLNL) Site 300 - Pit 6 Landfill Operable Unit (OU), Livermore, CA.

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Site Information:

- AFCEE action, Fairchild AFB, WA
- DOE Oak Ridge, TN facility
- Lawrence Livermore National Laboratory, Site 300, Coast Ranges, CA
- DOE Demo, Lee Acres landfill, Farmington, NM
- Lawrence Livermore National Laboratory, Site 300, Pit 6 Landfill OU, Livermore, CA
- Seymour Recycling Corporation Superfund Site, Seymour, IN
- Sylvester/Gilson Road Superfund Site, Nashua, NH

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Technology Specific Web Sites:

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Vendor Information:

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A list of vendors offering Soil Containment Treatment is available is from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.7 Containment
>>4.27 Landfill Cap Enhancements

Introduction>> The purpose of landfill cover enhancement is to reduce or eliminate contaminant migration (e.g. percolation). Water harvesting and vegetative cover are two ways for landfill cover enhancements. Water harvesting uses runoff enhancement to manage landfill site water balance. Vegetative cover reduces soil moisture via plant uptake and evapotranspiration.

Description:

Figure 4-27: Typical Water Harvesting Enhancement

The precipitation to the landfill cover is balanced by the combination of following effects: run-off, cumulating in soil, evapotranspiration, and percolation. For a given amount of precipitation, in order to reduce or eliminate percolation, the effects of run-off and/or evapotranspiration need to be enhanced.

➢ *Water Harvesting*

Water harvesting uses runoff enhancement to manage landfill site water balance. This enhancement can be achieved by simply covering landfill cover surface with metal rain gutter placed parallel to the slope. The percentage of runoff increases when gutter coverage increases. However, too much coverage (> 40%) has little effect on runoff enhancement.

➢ *Vegetative Cover*

Vegetative cover reduces soil moisture via plant uptake and evapotranspiration. Plant cover also limits soil erosion. Vegetative cover is more stable because it emphasizes use of natural materials and configurations, which implies longevity.

TOP

Synonyms:

NA

TOP

Applicability:

Landfill cover enhancement is applicable for traditional landfills, surface impoundment's, waste piles, sludges, and some mine tailings. It may prove to be less costly than a conventional barrier because it uses simple structure or local resources. It is simple in design, easy to install over an existing landfill cover, and easy to remove if other uses for the land emerge in the future.

TOP

Limitations:

Factors that may limit the applicability and effectiveness of these processes include:

- Proper site evaluation is required.
- Plant coverage is seasonal.
- Too much gutter coverage (> 40%) has little effect on runoff enhancement.

TOP

Data Needs:

A detailed discussion of data elements is provided in Subsection 2.2.1 (Data Requirements for Soil, Sediment, and Sludge).

TOP

Performance Data:

Landfill cover enhancement is a fairly new technology that is still being tested and demonstrated.

Naval Facilities Engineering Services Center initiated a demonstration project at Marine Corp Base Hawaii to evaluate infiltration control cover design. Metal rain gutters were placed on the ground surface and parallel to the slope. Remaining surface was seeded with 6 native grasses and shrubs. After 9 months of operation, it was found that plots with runoff enhancement had 2 to 5 times more runoff, and 2 to 3 times less percolation.

TOP

Cost:

The simple configuration of landfill cover enhancement should result better containment with little increase in costs. These costs are currently determined on a case-by-case basis because of construction material availability and design requirements at various site locations.

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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AFCEE/ERT, 1999. Landfill Covers for Use at Air Force Installations.

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Site Information:

- DOE Demonstration, Sandia National Laboratories
- MCAS Kaneohe Bay

Points of Contact:

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Government Disclaimer

Health and Safety:

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Technology>> Soil, Sediment, Bedrock and Sludge
>>3.8 Other Treatment
>>4.28 Excavation, Retrieval, and Off-Site

Introduction>> Contaminated material is removed and transported to permitted off-site treatment and disposal facilities. Pretreatment may be required.

Description:

Figure 4-28: Typical Contaminated Soil Excavation Diagram 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.

Confined disposal facilities (CDFs) are engineered structure enclosed by dikes and designed to retain dredged materials. A CDF may have a large cell for material disposal, and adjoining cells for retention and decantation of turbid, supernatant water. A variety of linings have been used to prevent seepage through the dike walls. The most effective are clay or bentonite-cement slurries, but sand, soil, and sediment linings have also been used.

Location and design are two important CDF consideration. Terms to consider in the location of a CDF are the physical aspects (size, proximity to a navigable waterway), the design/construction (geology/hydrology), and the environmental (current use of the area, environmental value, and environmental effects). The primary goal of a CDF design is minimization of contaminant loss. Caps are the most effective way to minimize contaminant loss from CDFs, but selection of proper liner material is also an important control on CDFs. Finally, CDFs require continuous monitoring to ensure structural integrity.

Operation and maintenance duration lasts as long as the life of the facility.

TOP

Synonyms:

DSERTS Codes:

E0 (Removal)
E1 (Waste Removal-Soils)
R1 (Waste Removal-Sludges)
S1 (Waste Removal-Non-soil Solids)

TOP

Applicability:

Excavation and off-site disposal is applicable to the complete range of contaminant groups with no particular target group. Excavation and off-site by relocating the waste to a different (and presumably safer) site.

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 with the required permit(s) 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.
- Contaminants can potentially migrate from CDF from several pathways, including effluent discharge to surface water, rainfall surface runoff, leachate into ground water, volatilization to the atmosphere, and dike uptake.
- CDFs can develop odor problems as well as mosquito and insect problems without proper design and maintenance.

TOP

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.

TOP

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.

The rate of excavation depends on a number of factors, including the number of loaders and trucks operating. The excavation of 18,200 metric tons (20,000 tons) of contaminated soil would typically require about 2 months. Disposal of the contaminated media is dependent upon the availability of adequate containers to transport the hazardous waste to a 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 (LN2) 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.

TOP

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.

Additional cost of treatment at disposal facility may also be required. 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.

Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes (HTRW) Historical Cost Analysis System (HCAS) developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group.

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References:

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EPA, 1997. *Best Management Practices (BMPs) for Soil Treatment Technologies: Suggested Operational Guidelines to Prevent Cross-media Transfer of Contaminants During Clean-UP Activities*, EPA OSWER, EPA/530/R-97/007.

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Site Information:

- EPA Demo: Carter Industrial, MI; Shaver's Farm, GA; Hopkinsville, KY
- EPA Demo:IN, MI, OH, SD, VA, WI
- DOE Integrated Demo: (1,2) Chemical and Mixed Waste Landfills, Albuquerque, NM; (3) Mixed Waste Landfill at Kirkland AFB, NM
- DOE Integrated Demo: Fernald Environmental Project Cincinnati, OH

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A list of vendors offering Soil Excavation, Retrieval, and Off-Site Disposal Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Technology>> Ground Water, Surface Water, and Leachate
>>3.9 In Situ Biological Treatment
>>4.29 Enhanced Bioremediation

Introduction>> The rate of bioremediation of organic contaminants by microbes is enhanced by increasing the concentration of electron acceptors and nutrients in ground water, surface water, and leachate. Oxygen is the main electron acceptor for aerobic bioremediation. Nitrate serves as an alternative electron acceptor under anoxic conditions.

Description:

Figure 4-29a:
Typical Oxygen-Enhanced Bioremediation System for Contaminated Ground water with Air Sparging

Figure 4-29b:
Oxygen-Enhanced H_2O_2 Bioremediation System

Figure 4-29c:
Typical Nitrate-Enhanced Bioremediation System

Bioremediation is a process in which indigenous or inoculated micro-organisms (i.e., fungi, bacteria, and other microbes) degrade (metabolize) organic contaminants found in soil and/or ground water.

Bioremediation is a process that attempts to accelerate the natural biodegradation process by providing nutrients, electron acceptors, and competent degrading microorganisms that may otherwise be limiting the rapid conversion of contamination organics to innocuous end products.

Oxygen enhancement can be achieved by either sparging air below the water table or circulating hydrogen peroxide (H_2O_2) throughout the contaminated ground water zone. Under anaerobic conditions, nitrate is circulated throughout the ground water contamination zone to enhance bioremediation. Additionally, solid-phase peroxide products (e.g., oxygen releasing compound (ORC)) can also be used for oxygen enhancement and to increase the rate of biodegradation.

➢ *Oxygen Enhancement with Air Sparging*

Air sparging below the water table increases ground water oxygen concentration and enhances the rate of biological degradation of organic contaminants by naturally occurring microbes. (VOC stripping enhanced by air sparging is addressed in Technology Profile 4.34). Air sparging also increases mixing in the saturated zone, which increases the contact between ground water 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.

➢ *Oxygen Enhancement with Hydrogen Peroxide*

During hydrogen peroxide enhancement, a dilute solution of hydrogen peroxide is circulated through the contaminated ground water zone to increase the oxygen content of ground water and enhance

the rate of aerobic biodegradation of organic contaminants by naturally occurring microbes.

➢ *Nitrate Enhancement*

Solubilized nitrate is circulated throughout ground water contamination zones to provide an alternative electron acceptor for biological activity and enhance the rate of degradation of organic contaminants. Development of nitrate enhancement is still at the pilot scale. 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 and because oxygen is rapidly consumed by aerobic microbes. Nitrate also can serve as an electron acceptor 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. The benzene component of fuel has been found to biodegrade slower 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.

These technologies may be classified as long-term technologies, which may take several years for plume clean-up.

TOP

Synonyms:

Biostimulation, bioaugmentation.
DSERTS Codes:

F11 (Bioremediation - In Situ Groundwater)
H1 (Bioremediation)
H12 (Bioremediation - In Situ)

TOP

Applicability:

Target contaminants for enhanced biodegradation processes are nonhalogenated VOCs, nonhalogenated SVOCs, and fuels. Pesticides also should have limited treatability. Nitrate enhancement has primarily been used to remediate ground water contaminated by BTEX.

TOP

Limitations:

Factors that may limit the applicability and effectiveness of these processes include:

- Where the subsurface is heterogeneous, it is very difficult to deliver the nitrate or hydrogen peroxide solution throughout every portion of the contaminated zone. Higher permeability zones will be cleaned up much faster because ground water flow rates are greater.
- Safety precautions must be used when handling hydrogen peroxide.
- Concentrations of hydrogen peroxide greater than 100 to 200 ppm in ground water are inhibiting to microorganisms.
- Microbial enzymes and high iron content of subsurface materials can rapidly reduce concentrations of hydrogen peroxide and reduce zones of influence.
- A ground water circulation system must be created so that contaminants do not escape from zones of active biodegradation.
- Because air sparging increases pressure in the vadose zone, vapors can build up in building basements, which are generally low pressure areas.
- Many states prohibit nitrate injection into ground water because nitrate is regulated through drinking water standards.
- A surface treatment system, such as air stripping or carbon adsorption, may be required to treat extracted ground water 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 Ground Water, 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, redox conditions, temperature, biodegradability of contaminants, and the presence of a competent biodegrading population of microorganisms.

TOP

Performance Data:

As with other in situ biodegradation processes, the success of this technology is highly dependent upon soil properties and biodegradability of the contaminants.

Although oxygen enhancement with air sparging is relatively new, the related technology, bioventing (Treatment Technology Profile 4.1), 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 ground water.

TOP

Cost:

For oxygen enhancement with air sparging, typical costs are $10 to $20 per 1,000 liters ($40 to $80 per 1,000 gallons) of ground water treated. Variables affecting the cost are the nature and depth of the contaminants, use of bioaugmentation and/or hydrogen peroxide or nitrate addition, and ground water pumping rates.

For nitrate enhanced treatment, 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.

For hydrogein peroxide enhanced treatment, costs are an order of magnitude more expensive than other methods of oxygen enhancement. O&M cost of hydrogen peroxide enhancement can be significant because a continuous source of hydrogen peroxide must be delivered to the contaminated ground water.

TOP

References:

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Federal Remediation Technologies Roundtable, 1997. *Remediation Case Studies: Soil Vapor Extraction and Other In Situ Technologies*, EPA/542/R-97/009.

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- Enhanced Bioremediation of Contaminated Groundwater - Balfour Road Site, Brentwood, CA; Fourth Plain Service Station Site, Vancouver, WA; Steve's Standard and Golden Belt 66 Site, Great Bend, KS
- In Situ Anaerobic Bioremediation at DOE's Pinellas Northeast Site, Largo, Florida
- Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the French Ltd. Superfund Site, Crosby, Texas
- Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the Libby Groundwater Superfund Site, Libby, Montana
- Pump and Treat, In Situ Bioremediation, and In Situ Air Sparging of Contaminated Groundwater at Site A, Long Island, New York

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Treatment Technologies Applications Matrix for Base Closure Activities, November 1994

U.S. Department of Commerce, National Technical Information Service(NTIS), May 1991. "Nitrate for Biorestoration of an Aquifer Contaminated with Jet Fuel".

TOP

Site Information:

- Watertown, MA
- Bendena Site, KS
- UST site 23, Naval Air Station Point Mugu, CA
- Natural Gas Pipeline Compressor Station, VA
- Unidentified Site, Lansing, MI
- Formerly JimBo's Gas N'Goodies, Aiken, SC
- Dry Cleaning Facility
- Columbia County Landfill, GA
- Denver Federal Center, CO
- Hanford 200 Area
- ORNL, Oak Ridge, TN
- Edwards AFB, CA
- Naval Communication Station, Scotland
- DOE Demo Savannah River Site, SC
- EPA Demo Williams AFB, AZ
- DOE Savannah River Site, SC
- DOE Demo Hanford Site, WA
- NAS Fallon, NV
- Air Force & DOE Demo Tinker AFB, OK
- Air Force Demo Eglin, AFB, FL
- Air Force Demo Kelly AFB, TX & Eglin AFB, FL
- DOI Demo Picatinny Arsenal, NJ
- DOI Demo Defense Fuel Supply Point, SC
- DOE Tech Demo (USGS) Galloway Township, NJ
- Stalworth Timber Beatrice, AL
- Park City, KS
- Mayville Fire Department Mayville, MI
- Dover AFB, Dover, DE
- Knispel Construction Site, Horseheads, NJ
- Orkin Facility, Fort Pierce, FL
- Farfield Coal & Gas, Farfield, IA
- DOE K-25 Site
- Libby Ground Water Superfund Site
- Public Service Company of Colorado, CO
- Kennedy Space Center, FL
- DOE's Portsmouth Gaseous Diffusion Plant, X-231B Unit, Piketon, OH
- Balfour Road Site, Brentwood, CA; Fourth Plain Service Station Site, Vancouver, WA; Steve's Standard and Golden Belt 66 Site, Great Bend, KS
- DOE's Pinellas Northeast Site, Largo, FL
- French Ltd. Superfund Site, Crosby, TX
- Site A, Long Island, NY
- Additional site information on the FRTR web site

Points of Contact:

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Non Government Web Sites

Vendor Information:

TOP

A list of vendors offering In Situ Biological Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and

their applications.

Government Disclaimer

Health and Safety:

TOP

Hazard Analysis

TOP

Technology>> Ground Water, Surface Water, and Leachate
>>3.9 In Situ Biological Treatment
>>4.30 Monitored Natural Attenuation

Introduction>> Natural subsurface processes—such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials—are allowed to reduce contaminant concentrations to acceptable levels.

Description:

Figure 4-30:
Typical Monitoring Well Construction Diagram 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 usually requires modeling and evaluation of contaminant degradation rates and pathways and predicting contaminant concentration at down gradient receptor points, especially when plume is still expanding/migrating. The primary objective of site modeling is to demonstrate that natural processes of contaminant degradation will reduce contaminant concentrations below regulatory standards or risk-based levels before potential exposure pathways are completed. In addition, long term monitoring must be conducted throughout the process to confirm that degradation is proceeding at rates consistent with meeting cleanup objectives.

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.

Compared with other remediation technologies, natural attenuation has the following advantages:

- Less generation or transfer of remediation wastes;
- Less intrusive as few surface structures are required;
- May be applied to all or part of a given site, depending on site conditions and cleanup objectives;
- Natural attenuation may be used in conjunction with, or as a follow-up to, other (active) remedial measures; and
- Overall cost will likely be lower than active remediation.

TOP

Synonyms:

Intrinsic Remediation; Bioattenuation; Intrinsic Bioremediation; Monitored Natural Attenuation (MNA).
DSERTS Code: F3 (Natural Attenuation)

TOP

Applicability:

Target contaminants for natural attenuation are VOCs and SVOCs and fuel hydrocarbons. Fuel and halogenated VOCs are commonly evaluated for natural attenuation. Pesticides also can be allowed to naturally attenuate, but the process may be less effective and may be applicable to only some compounds within the group. Additionally, natural attenuation may be appropriate for some metals when natural attenuation processes result in a change in the valence state of the metal that results in immobilization (e.g., chromium).

TOP

Limitations:

Factors that may limit applicability and effectiveness include:

- Data used as input parameters for modeling need be collected.
- Intermediate degradation products may be more mobile and more toxic than the original contaminant.
- Natural attenuation is not appropriate where imminent site risks are present.
- Contaminants may migrate before they are degraded.
- Institutional controls may be required, and the site 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.
- Long term monitoring and associated costs.
- Longer time frames may be required to achieve remediation objectives, compared to active remediation.
- The hydrologic and geochemical conditions amenable to natural attenuation are likely to change over time and could result in renewed mobility of previously stabilized contaminants and may adversely impact remedial effectiveness; and
- More extensive outreach efforts may be required in order to gain public acceptance of natural attenuation.

TOP

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 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).

Although many potential suppliers perform the modeling, sampling, and sample analysis required for monitoring natural attenuation, the evaluation of natural attenuation is often not straightforward and will require expertise in several technical areas including microbiology/bioremediation, hydrogeology, and geochemistry. When available, information to be obtained during data review includes:

- Soil and ground water 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.
  - Historical water quality data showing variations in contaminant concentrations through time.
  - Chemical and physical characteristics of the contaminants.
  - Geochemical data to assess the potential for biodegradation of the contaminants.

- Location of potential receptors:
  - Ground water wells.
  - Surface water discharge points.

The operation and maintenance (O&M) duration is determined from natural attenuation evaluation and regulatory requirements. The process is expected to continue for several years until desired degradation levels are achieved. The duration of O&M is dependent on all of the data and information listed above.

TOP

Performance Data:

Natural attenuation has been selected by AFCEE for remediation at 45 sites.

TOP

Cost:

There are costs for modeling and monitoring. Modeling determines whether natural attenuation is a feasible remedial alternative. The most significant costs associated with natural attenuation are most often due to monitoring requirements, which include two major parts - site characterization and performance monitoring. Site characterization determines the extent of contamination and contaminant degradation rates. Performance monitoring tracks down contaminants migration and degradation and cleanup status.

TOP

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A Citizen's Guide to Monitored Natural Attenuation (English Version), EPA 542-F-01-004

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Weidemeier, T.H., B. Blicker, and P.R. Guest, 1994b. "Risk-Based Approach to Bioremediation of Fuel Hydrocarbons at a Major Airport," in *Proceedings of the Federal Environmental Restoration III & Waste Minimization Conference & Exhibition.*

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.

TOP

Site Information:

- Columbus AFB, MS

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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Government Disclaimer

Health and Safety:

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To be added

TOP

Technology>> Ground Water, Surface Water, and Leachate
>>3.9 In Situ Biological Treatment
>>4.31 Phytoremediation

Introduction>> Phytoremediation is a set of processes that uses plants to remove, transfer, stabilize and destroy organic/inorganic contamination in ground water, surface water, and leachate.

Description:

Figure 4-31 Typical In Situ Phytoremediation System Phytoremediation is a set of processes that uses plants to clean contamination in ground water and surface water. The treatment of metals or other inorganic contamination has been discussed in Section 4.6 (Phytoremediation for Soil). There are several ways plants can be used for the phytoremediation. These mechanisms include enhanced rhizosphere biodegradation, hydraulic control, phyto-degradation and phyto-volatilization.

➢ *Enhanced Rhizosphere Biodegradation*

Enhanced rhizosphere biodegradation takes place in the soil surrounding plant roots. Natural substances released by plant roots supply nutrients to microorganisms, which enhances their ability to biodegrade organic contaminants. Plant roots also loosen the soil and then die, leaving paths for transport of water and aeration. This process tends to pull water to the surface zone and dry the lower saturated zones.

➢ *Hydraulic Control*

Depending on the type of trees, climate, and season, trees can act as organic pumps when their roots reach down towards the water table and establish a dense root mass that takes up large quantities of water.

➢ *Phyto-degradation*

Phyto-degradation is the metabolism of contaminants within plant tissues. Plants produce enzymes, such as dehalogenase and oxygenase, that help catalyze degradation. Investigations are proceeding to determine if both aromatic and chlorinated aliphatic compounds are amenable to phyto-degradation.

➢ *Phyto-volatilization*

Phyto-volatilization occurs as plants take up water containing organic contaminants and release the contaminants into the air through their leaves. Plants can also break down organic contaminants and release breakdown products into air through leaves.

TOP

Synonyms:

Vegetation-enhanced bioremediation.

TOP

Applicability:

Phytoremediation can be used to clean up organic contaminants from surface water, ground water, leachate, and municipal and industrial wastewater.

Plants also produce enzymes, such as dehalogenase and oxygenase, which help catalyze degradation.

TOP

Limitations:

There are a number of limitations to phytoremediation

- It is limited to shallow soils, streams, and ground water.
- High concentrations of hazardous materials can be toxic to plants.
- It involves the same mass transfer limitations as other biotreatments.
- Climatic or seasonal conditions may interfere or inhibit plant growth, slow remediation efforts, or increase the length of the treatment period.
- It can transfer contamination across media, e.g., from soil to air.
- It is not effective for strongly sorbed (e.g., PCBs) and weakly sorbed contaminants.
- Phytoremediation will likely require a large surface area of land for remediation.
- The toxicity and bioavailability of biodegradation products is not always known. Products may be mobilized into ground water or bioaccumulated in animals. More research is needed to determine the fate of various compounds in the plant metabolic cycle to ensure that plant droppings and products manufactured by plants do not contribute toxic or harmful chemicals into the food chain or increase risk exposure to the general public.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2. (Data Requirements for Ground Water, Surface Water, and Leachate).

In addition, detailed information is needed to determine the kinds of soil used for phytoremediation projects. Water movement, reductive oxygen concentrations, root growth, and root structure all affect the growth of plants and should be considered when implementing phytoremediation.

TOP

Performance Data:

The U.S. Air Force used poplar trees to contain a ground water TCE plume. TCE was shown to be degraded in the tissues of the poplar trees. The trees pumped a sufficient amount of water to produce a cone of depression limiting the spread of the TCE plume.

In Iowa, EPA demonstrated the usage of phytoremediation by planting poplar trees along a stream bank between a corn field and the stream. These trees acted as natural pumps to keep toxic herbicides, pesticides, and fertilizers out of the streams and ground water. After three years, while the nitrate concentration in ground water at the edge of the corn field was measured at 150 mg/L, the ground water among the poplar trees along the stream bank had nitrate concentration of only 3 mg/L.

USAEC is also leading the team of experts from EPA, Tennessee Valley Authority (TVA) and the Waterways Experimental Station (WES) to successfully demonstrate phytoremediation of explosive contaminated sites in Milan Army Ammunition Plant in Milan, TN.

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Scale of effort
    - Area of contamination is the primary cost driver
- Tree size (maturity) is the secondary cost driver.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply phytoremediation technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

GW TECHNOLOGY:	Phytoremediation			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER SQUARE FOOT	**$1.52**	**$1.69**	**$0.45**	**$0.64**

Detailed Cost Estimate

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

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TOP

Site Information:

- Chevron, Ogden, UT
- Aberdeen, MD
- Ogden, UT
- U.S Air Force Facility, Fort Worth, TX
- Milan Army Ammunition Plant (USAEC), TN
- DOE, Bear Creek, Oak Ridge National Laboratory, TN

Points of Contact:

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Government Disclaimer

Health and Safety:

TOP

To be added

TOP

Technology>> Ground Water, Surface Water, and Leachate >>3.10 In Situ Physical/Chemical Treatment >>4.32 Air Sparging

Introduction>> Air is injected into saturated matrices to remove contaminants through volatilization.

Description:

Figure 4-32:
Typical Air Sparging System Air sparging is an in situ technology in which air is injected through a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper that removes contaminants by volatilization. This injected air helps to flush (bubble) the contaminants up into the unsaturated zone where a vapor extraction system is usually 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 ground water and soil and strip more ground water by sparging.

Oxygen added to contaminated ground water and vadose zone soils can also enhance biodegradation of contaminants below and above the water table.

Air sparging has a medium to long duration which may last, generally, up to a few years.

TOP

Synonyms:

In-situ air sparging, in-situ aeration.
DSERTS Code: F14 (Air Sparging)

TOP

Applicability:

The target contaminant groups for air sparging are VOCs and fuels. Only limited information is available on the process. Methane can be used as an amendment to the sparged air to enhance cometabolism of chlorinated organics.

TOP

Limitations:

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

- Air flow through the saturated zone may not be uniform, which implies that there can be uncontrolled movement of potentially dangerous vapors.

- Depth of contaminants and specific site geology must be considered.
- Air injection wells must be designed for site-specific conditions.
- Soil heterogeneity may cause some zones to be relatively unaffected.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2. (Data Requirements for Ground Water, Surface Water, and Leachate). Characteristics that should be determined include vadose zone gas permeability, depth to water, ground water flow rate, radial influence of the sparging well, aquifer permeability and heterogeneities, presence of low permeability layers, presence of DNAPLs, depth of contamination, and contaminant volatility and solubility. Additionally, it is often useful to collect air-saturation data, in the saturated zone, during an air sparging test, using a neutron probe.

TOP

Performance Data:

This technology is demonstrated at numerous sites, though only a few sites are well documented. Air sparging has demonstrated sensitivity to minute permeability changes, which can result in localized stripping between the sparge and monitoring wells.

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Surface area (contaminant orientation)
  - Surface area of contamination is the primary cost driver, and directly affects the quantity of air sparge points.
- Depth to Contamination
  - Depth is the secondary cost driver. Cost increases with depth since it impacts the drilling costs.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply air sparging technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

GW TECHNOLOGY:	Air Sparging			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER CUBIC FOOT	$2	$1	$0.67	$0.75
COST PER CUBIC METER	$84	$37	$24	$27

COST PER CUBIC YARD	$64	$28	$18	$20

Detailed Cost Estimate

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Treatment Experiences at RCRA Corrective Actions, December 2000, EPA 542-F-00-020

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

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DOE, 1994. *Technology Application Analysis: Density-Driven Groundwater Sparging at Amcor Precast Ogden,Utah*, prepared by Stone & Webster Environmental Technology & Services.

EPA, 1995. *Remediation Case Studies: Groundwater Treatment*, Federal Remediation Technologies Roundtable Report, EPA/542/R-95/003.

EPA, 1997. *Analysis of Selected Enhancements for Soil Vapor Extraction*, EPA OSWER, EPA/542/R-97/007.

ESTCP Document, 1999. Draft Air Sparging Design Paradigm.

EPA, 2001. A Citizen's Guide to Soil Vapor Extraction and Air Sparging. EPA 542-F-01-006.

Federal Remediation Technologies Roundtable, 1995. *Remediation Case Studies: Bioremediation*, EPA/542/R-95/002.

- In Situ Bioremediation Using Horizontal Wells at the U.S. Department of Energy's Savannah River Site, M Area, Aiken, South Carolina

Federal Remediation Technologies Roundtable, 1995. *Remediation Case Studies: Groundwater Treatment*, EPA/542/R-95/003.

- Density-Driven Groundwater Sparging at Amcor Precast Ogden, Utah
- In Situ Air Stripping of Contaminated Groundwater at the U.S. Department of Energy's

Savannah River Site, A/M Area, Aiken, South Carolina
- Petroleum Product Recovery and Contaminated Groundwater Remediation at Amoco Petroleum Pipeline, Constantine, Michigan

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: In Situ Soil Treatment Technologies (Soil Vapor Extraction, Thermal Processes)*, EPA/542/R-98/012

- Air Sparging, In Situ Bioremediation, and Soil Vapor Extraction at the Texas Tower Site, Fort Greely, Alaska
- Air Sparging and Soil Vapor Extraction at Landfill 4, Fort Lewis, Washington

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Innovative Groundwater Treatment Technologies*, EPA/542/R-98/015.

- Pump and Treat and Air Sparging of Contaminated Groundwater at the Gold Coast Superfund Site, Miami, Florida
- Pump and Treat, In Situ Bioremediation, and In Situ Air Sparging of Contaminated Groundwater at Site A, Long Island, New York

Hildebrandt, W. and F. Jasiulewicz, 1992. "Cleaning Up Military Bases," *The Military Engineer,* No. 55, p. 7, September-October 1992.

USACE, 1997. *In Situ Air Sparging Engineer Manual,* EM 1110-1-4005.

Treatment Technologies Applications Matrix for Base Closure Activities, November 1994

TOP

Site Information:

- Fort Drum, Watertown, NY
- DOE Demo Hanford Reservation, WA
- DOE Integrated Demo, DOE Savannah River Site, Aiken, GA
- Denison Avenue Site, Cleveland, OH
- NEL Demo: NAS North Island Installation Restoration (IR) Site 11
- Gold Coast Superfund Site, Miami, FL
- Department of Energy's Savannah River Site, M Area, Aiken, SC
- Texas Tower Site, Fort Greely, AK
- Landfill 4, Fort Lewis, WA
- Amcor Precast, Ogden, UT
- DOE's Savannah River Site, A/M Area, Aiken, SC
- Amoco Petroleum Pipeline, Constantine, MI
- Site A, Long Island, NY
- Additional site information on the FRTR web site

Points of Contact:

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Technology Specific Web Sites:

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Vendor Information:

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A list of vendors offering In Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and

Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Technology>> Ground Water, Surface Water, and Leachate
>>3.10 In Situ Physical/Chemical Treatment
>>4.33 Bioslurping

Introduction>> Bioslurping combines the two remedial approaches of bioventing and vacuum-enhanced free-product recovery. Bioventing stimulates the aerobic bioremediation of hydrocarbon-contaminated soils. Vacuum-enhanced free-product recovery extracts LNAPLs from the capillary fringe and the water table.

Description:

Figure 4-33:
Typical In Situ Bioslurping System

Bioslurping is the adaptation and application of vacuum-enhanced dewatering technologies to remediate hydrocarbon-contaminated sites. Bioslurping utilizes elements of both, bioventing and free product recovery, to address two separate contaminant media. Bioslurping combines elements of both technologies to simultaneously recover free product and bioremediate vadose zone soils. Bioslurping can improve free-product recovery efficiency without extracting large quantities of ground water. In bioslurping, vacuum-enhanced pumping allows LNAPL to be lifted off the water table and released from the capillary fringe. This minimizes changes in the water table elevation which minimizes the creation of a smear zone. Bioventing of vadose zone soils is achieved by drawing air into the soil due to withdrawing soil gas via the recovery well. The system is designed to minimize environmental discharge of ground water and soil gas. When free-product removal activities are completed, the bioslurping system is easily converted to a conventional bioventing system to complete the remediation.

Operation and maintenance duration for bioslurping varies from a few months to years, depending on specific site conditions.

TOP

Synonyms:

Free product recovery.

TOP

Applicability:

Bioslurping can be successfully used to remediate soils contaminated by petroleum hydrocarbons. It is a cost-effective in situ remedial technology that simultaneously accomplishes LNAPL removal and soil remediation in the vadose zone. Bioslurping is also applicable at sites with a deep ground water table (>30ft.).

TOP

Limitations:

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

- Bioslurping is less effective in tight (low-permeability) soils.
- Low soil moisture content may limit biodegradation and the effectiveness of bioventing, which tends to dry out the soils.
- Aerobic biodegradation of many chlorinated compounds may not be effective unless there is a co-metabolite present.
- Low temperatures slow remediation.
- Frequently, the off-gas from the bioslurper system requires treatment before discharge. However, treatment of the off-gas may only be required shortly after the startup of the system as fuel rates decrease.
- At some sites, bioslurper systems can extract large volumes of water that may need to be treated prior to discharge depending on the concentration of contaminants in the process water.
- Since the fuel, water and air are removed from the subsurface in one stream, mixing of the phases occurs. These mixtures may require special oil/water separators or treatment before the process water can be discharged.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2. (Data Requirements for Ground Water, Surface Water, and Leachate). Determination of the radius of treatment influence and number of extraction wells during the feasibility study and pilot-scale testing is critical for the lay-out design of a full-scale bioslurping application. Additionally, a feasibility test and an air permeability test are necessary to determine design data, including time of release, quantity of release, and free product thickness.

Soil grain size and soil moisture significantly influence soil gas permeability. Perhaps the greatest limitation to air permeability is excessive soil moisture. A combination of high water tables, high moisture, and fine-grained soils has made bioslurping infeasible. Optimum soil moisture is very soil-specific because too much moisture can reduce the air permeability of the soil and decrease its oxygen transfer capability. Too little moisture will inhibit microbial activity.

In situ aeration/respiration testing is also needed to provide rapid field measurement of the in situ degradation rate.

TOP

Performance Data:

The U.S. Navy has used bioslurping at Naval Aviation Facility in Fallon, NV. This system was able to remove 6,500 gallons of JP-5 jet fuel during 1993, with operation 75% of the time. Bioslurping will also be initiated at MCAS Kaneohe Bay HI, which has extensive subsurface plumes of JP-5.

The U.S. Air Force used a bioslurper on the island of Diego Garcia to pull out JP-5 at the site where jet fuel leaked into the ground during the Persian Gulf War. The recovery rate of JP-5 averaged about 1,000 gallons per month.

TOP

Cost:

Bioslurping of LNAPL at Multiple Air Force Sites was $56/gal LNAPL recovered.

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

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Baker, R.S. and J.Bierschenk, 1996. "Bioslurping LNAPL contamination". *Pollution Engineering*, March, pp.38-40.

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USAF, 1994. *Technology Profile: Vacuum-Mediated LNAPL Free Product Recovery/Bioremediation (Bioslurper)*, Air Force Center for Environmental Excellence (AFCEE), Brooks AFB, TX. March.

USAF, January 1995. *Draft: Test Plan and Technical Protocol for Bioslurping*, USAF, Air Force Center for Environmental Excellence, Brooks AFB, TX.

Wickramanayake, G.B., et al., 1996. "Best Practices Manual for Bioslurping", *Technical Memorandum*, Naval Facilities Engineering Service Center, TM-2192-ENV.

TOP

Site Information:

- Island of San Diego Garcia, AFCEE/PA, Brooks AFB, TX
- Naval Air Station, Fallon, Nevada
- Additional site information on the FRTR web site

Points of Contact:

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General FRTR Agency Contacts

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A list of vendors offering In Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

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Technology>> Ground Water, Surface Water, and Leachate >>3.10 In Situ Physical/Chemical Treatment >>4.34 Chemical Oxidation

Introduction>> 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.

Description:

Figure 4-34: Typical Chemical Oxidation System

The Chemical oxidants most commonly employed to date include peroxide, ozone, and permanganate. These oxidants have been able to cause the rapid and complete chemical destruction of many toxic organic chemicals; other organics are amenable to partial degradation as an aid to subsequent bioremediation. In general the oxidants have been capable of achieving high treatment efficiencies (*e.g.*, > 90 percent) for unsaturated aliphatic (*e.g.*, trichloroethylene [TCE]) and aromatic compounds (*e.g.*, benzene), with very fast reaction rates (90 percent destruction in minutes). Field applications have clearly affirmed that matching the oxidant and *in situ* delivery system to the contaminants of concern (COCs) and the site conditions is the key to successful implementation and achieving performance goals.

➢ *Peroxide*

Oxidation using liquid hydrogen peroxide (H_2O_2) in the presence of native or supplemental ferrous iron (Fe^{+2}) produces Fenton's Reagent which yields free hydroxyl radicals (OH^-). These strong, nonspecific oxidants can rapidly degrade a variety of organic compounds. Fenton's Reagent oxidation is most effective under very acidic pH (e.g., pH 2 to 4) and becomes ineffective under moderate to strongly alkaline conditions. The reactions are extremely rapid and follow second-order kinetics.

➢ *Ozone addition*

Ozone gas can oxidize contaminants directly or through the formation of hydroxyl radicals. Like peroxide, ozone reactions are most effective in systems with acidic pH. The oxidation reaction proceeds with extremely fast, pseudo first order kinetics. Due to ozone's high reactivity and instability, O_3 is produced onsite, and it requires closely spaced delivery points (*e.g.*, air sparging wells). *In situ* decomposition of the ozone can lead to beneficial oxygenation and biostimulation.

➢ *Permanganate*

The reaction stoichiometry of permanganate (typically provided as liquid or solid $KMnO_4$, but also available in Na, Ca, or Mg salts) in natural systems is complex. Due to its multiple valence states and mineral forms, Mn can participate in numerous reactions. The reactions proceed at a somewhat slower rate than the previous two reactions, according to second order kinetics. Depending on pH, the reaction can include destruction by direct electron transfer or free radical advanced oxidation—

permanganate reactions are effective over a pH range of 3.5 to 12.

TOP

Synonyms:

DSERTS Code: N13 (Chemical Reduction/Oxidation).

TOP

Applicability:

The rate and extent of degradation of a target COC are dictated by the properties of the chemical itself and its susceptibility to oxidative degradation as well as the matrix conditions, most notably, pH, temperature, the concentration of oxidant, and the concentration of other oxidant-consuming substances such as natural organic matter and reduced minerals as well as carbonate and other free radical scavengers. Given the relatively indiscriminate and rapid rate of reaction of the oxidants with reduced substances, the method of delivery and distribution throughout a subsurface region is of paramount importance. Oxidant delivery systems often employ vertical or horizontal injection wells and sparge points with forced advection to rapidly move the oxidant into the subsurface.

Permanganate is relatively more stable and relatively more persistent in the subsurface; as a result, it can migrate by diffusive processes. Consideration also must be given to the effects of oxidation on the system. All three oxidation reactions can decrease the pH if the system is not buffered effectively. Other potential oxidation-induced effects include: colloid genesis leading to reduced permeability; mobilization of redox-sensitive and exchangeable sorbed metals; possible formation of toxic byproducts; evolution of heat and gas; and biological perturbation

TOP

Limitations:

The following factors may limit the applicability and effectiveness of chemcial oxidation include:

- Requirement for handling large quantities of hazardous oxidizing chemicals due to the oxidant demand of the target organic chemicals and the unproductive oxidant consumption of the formation.
- Some COCs are resistant to oxidation.
- There is a potential for process-induced detrimental effects. Further research and development is ongoing to advance the science and engineering of *in situ* chemical oxidation and to increase its overall cost effectivenes.

TOP

Data Needs:

Engineering of *in situ* chemical oxidation must be done with due attention paid to reaction chemistry and transport processes. It is also critical that close attention be paid to worker training and safe handling of process chemicals as well as proper management of remediation wastes. The design and implementation process should rely on an integrated effort involving screening level characterization tests and reaction transport modeling, combined with treatability studies at the lab and field scale.

TOP

Performance Data:

In situ chemical oxidation is a viable remediation technology for mass reduction in source areas as well as for plume treatment. The potential benefits of *in situ* oxidation include the rapid and

extensive reactions with various COCs applicable to many bio-recalcitrant organics and subsurface environments. Also, *in situ* chemical oxidation can be tailored to a site and implemented with relatively simple, readily available equipment. Some potential limitations exist including the requirement for handling large quantities of hazardous oxidizing chemicals due to the oxidant demand of the target organic chemicals and the unproductive oxidant consumption of the formation; some COCs are resistant to oxidation; and there is a potential for process-induced detrimental effects. Further research and development is ongoing to advance the science and engineering of *in situ* chemical oxidation and to increase its overall cost effectiveness

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Economy of Scale
  - Quantity of material treated has a large impact
- Moisture content in waste
  - Slight increase in costs between soil and sludge
- Contaminant concentrations
  - High influent and low effluent concentrations will drive up costs

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply chemical oxidation technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

GW TECHNOLOGY:	Chemical Oxidation			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
Gallons processed	**21,024,000**	**21,024,000**	**262,800,000**	**262,800,000**
COST PER GALLON	**$0.02**	**$0.02**	**$0.003**	**$0.004**
COST PER 10,000 GALLONS	**$156**	**$175**	**$31**	**$39**

Detailed Cost Estimate

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

EPA, 2000.Ground Water Currents, December 2000, Issue No. 41: Current Issue: Interagency Demonstrations on DNAPL Conducted at Cape Canaveral

EPA, 2000.Ground Water Currents, September 2000, Issue No. 37: Current Issue: *In Situ* Chemical Oxidation for Remediation of Contaminated Soil and Ground Water

EPA, 1988, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, OSWER- 9355.3-01, Washington, DC

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Site Information:

- Additional site information on the FRTR web site

Points of Contact:

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Vendor Information:

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A list of vendors offering Water Containment Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Technology>> Ground Water, Surface Water, and Leachate >>3.10 In Situ Physical/Chemical Treatment >>4.35 Directional Wells

Introduction>> Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling.

Description:

Figure 4-35:
Typical Diagram of In Situ Air Stripping with Horizontal Wells

Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling. Directional drilling may be used to enhance other in-situ or in-well technologies such as ground water pumping, bioventing, SVE, soil flushing, and in-well air stripping.

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.

TOP

Synonyms:

Horizontal Wells.

TOP

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.

TOP

Limitations:

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

- 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.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2. (Data Requirements for Ground Water, Surface Water, and Leachate).

TOP

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/ground water 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.

TOP

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). Costs for installing a PVC or HDPE well using a small to medium sized utility-type drilling rig are projected as $164/m ($50/ft).

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References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

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.

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DOE, 1993. *Directional Boring and Thrusting with Hybrid Underground Utility Industry Equipment*, ProTech Database, TTP References: AL2211-16 and AL2211-03.

DOE, 1994. *Technology Catalogue*, First Edition. February.

DOE, 1993. *Technology Name: Slant-Angle Sonic Drilling, Technology Information Profile (Rev. 2)*, DOE ProTech Database, TTP Reference No.: AL2310-05.

EPA, 1994. *Manual: Alternative Methods for Fluid Delivery and Recovery*, Prepared by: Murdoch, L., and Wilson, D.D. EPA/625/R-94/003.

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Wilson, D.D., 1996. "Use of Horizontal Drilling In Environmental Remediation: A Horizontal Well Case Study", Water Well Journal, February.

Wilson, D.D., 1996, "Horizontal Well Development Made Easy", Water Well Journal, October.

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Site Information:

- DOE Demo Savannah River Site, SC

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering In Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

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Technology>> Ground Water, Surface Water, and Leachate >>3.10 In Situ Physical/Chemical Treatment >>4.36 Dual Phase Extraction

Introduction>> A high vacuum system is applied to simultaneously remove various combinations of contaminated ground water, separate-phase petroleum product, and hydrocarbon vapor from the subsurface.

Description:

Figure 4-36:
Typical Dual Phase Extraction Schematic

Dual-phase extraction (DPE), also known as multi-phase extraction, vacuum-enhanced extraction, or sometimes bioslurping, is a technology that uses a high vacuum system to remove various combinations of contaminated ground water, separate-phase petroleum product, and hydrocarbon vapor from the subsurface. Extracted liquids and vapor are treated and collected for disposal, or re-injected to the subsurface (where permissible under applicable state laws).

In DPE systems for liquid/vapor treatment, a high vacuum system is utilized to 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 ground water. It removes contaminants from above and below the water table. The system lowers the water table around the well, exposing more of the formation. Contaminants in the newly exposed vadose zone are then accessible to vapor extraction. Once above ground, the extracted vapors or liquid-phase organics and ground water are separated and treated. DPE for liquid/vapor treatment 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 ground water in higher-yielding aquifers.

TOP

Synonyms:

Multi-phase extraction; Vacuum-enhanced extraction; Free product recovery; Liquid-Liquid Extraction.
DSERTS Code:

(Dual-phase extraction)
F13 (Free product recovery)

TOP

Applicability:

The target contaminant groups for dual phase extraction are VOCs and fuels (e.g., LNAPLs). Dual phase vacuum extraction is more effective than SVE for heterogeneous clays and fine sands. However, it is not recommended for lower permeability formations due to the potential to leave isolated lenses of undissolved product in the formation.

Limitations:

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

- Site geology and contaminant characteristics/distribution.
- Combination with complementary technologies (e.g., pump-and-treat) may be required to recover ground water from high yielding aquifers.
- Dual phase extraction requires both water treatment and vapor treatment.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2. (Data Requirements for Ground Water, Surface Water, and Leachate).

Data needs include physical and chemical properties of the product released (e.g., viscosity, density, composition, depth, 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., permeability, depth to water table, ground water flow direction, and gradient); and anticipated product recharge rate.

TOP

Performance Data:

Once contaminants are detected, the immediate response should include both removal of the source and recovery of product by the most expedient means. Dual Phase Extraction methods will extract contaminated water with the product. It may be necessary to separate water and product 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.

TOP

Cost:

This cost estimate is does not include the costs for additional treatment steps which may be necessary when employing dual phase extraction technology such as the treatment and disposal of process residuals. The key cost driver information and cost analysis was developed using the 2006 version of the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Soil Type
    - Soil type determines permeability, which is the primary cost driver. Dual phase extraction works best for permeable sand-silt mixtures. Impermeable (clayey) or excessively permeable (gravel/sand) soils are more recalcitrant.
- Depth to Base of Contamination
    - Depth to the base of contamination is the secondary driver, as an increased thickness and depth of contaminated groundwater increases cost.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply dual

phase extraction technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

GW TECHNOLOGY:	Dual Phase Extraction			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
CUBIC YARDS PROCESSED	12,100	12,100	24,200	24,200
COST PER CUBIC YARD	$25	$55	$23	$52
COST PER 1000 CUBIC YARDS	$25,462	$54,545	$23,460	$52,381

Detailed Cost Estimate

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

American Petroleum Institute, 1989. *A Guide to the Assessment and Remediation of Underground Petroleum Releases*, Publication 1628, API, Washington, DC, 81 pp.

MTBE Treatment Case Studies presented by the USEPA Office of Underground Storage Tanks.

DOE, 1994. *Technology Application Analysis: Petroleum Product Recovery and Contaminated Groundwater Remediation Amoco Petroleum Pipeline Constantine, MI*, prepared by Stone & Webster Environmental Technology & Services.

DOE, 1994. *Technology Application Analysis: Recovery of Free Petroleum ProductFort Drum, Fuel Dispensing Area 1595 Watertown, New York*, prepared by Stone & Webster Environmental Technology & Services.

EPA, 1988. *Cleanup of Releases from Petroleum USTs: Selected Technologies*, Washington, DC, EPA/530/UST-88/001.

EPA, 1997. *Analysis of Selected Enhancements for Soil Vapor Extraction*, EPA OSWER, EPA/542/R-97/007.

FRTR, 1998. *Remediation Case Studies: Six Phase Soil Heating at the U.S. Department of Energy's Savannah River Site, M Area, Aiken, South Carolina; and Hanford Site, 300-Area, Richland, Washington.*

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.

TOP

Site Information:

- Amoco Petroleum Pipeline Constantine, MI
- Fort Drum, Watertown, NY
- March Air Force Base, CA
- Lockheed Aeronautical Systems Co., Burbank, CA
- Major Car Rental Agency, Los Angeles, CA
- Navy Fuel Farm
- Privately Owned Gasoline Station Near Urban Drinking Water Source
- Additional site information on the FRTR web site

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering In Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

TOP

Technology>> Ground Water, Surface Water, and Leachate >>3.10 In Situ Physical/Chemical Treatment >>4.37 Thermal Treatment

Introduction>> 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.

Description:

Figure 4-37:
Crow™ Subsurface Development Process

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 ground water contaminants concentrations satisfy statutory requirements.

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.

Hot water/steam injection is typically short to medium duration, lasting a few weeks to several months.

TOP

Synonyms:

Hydrous pyrolysis/oxidation; In situ steam extraction.
DSERTS Code: F15 (Hot water/steam flushting)

TOP

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, contaminant characteristics and concentrations, geology, and hydrogeology which will significantly impact process effectiveness.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2. (Data Requirements for Ground Water, Surface Water, and Leachate).

TOP

Performance Data:

Four vendors are promoting hot water or steam flushing/stripping processes. 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.

TOP

Cost:

The most significant factor affecting cost is the time of treatment or treatment rate. With the mobile system, treatment rate is influenced primarily by the soil type, waste type, and on-line efficiency. Cost estimates for this technology are strongly dependent on the treatment rate and range. On average, the cost ranges from $100 to $300 per cubic yard based on a 70 percent on-line efficiency.

In stationary *in situ* systems, the most significant factor influencing cost is the number of wells required per unit area, which is related to the depth of contamination, permeability and site geology. Shallow contamination requires lower operating pressures to prevent soil fracturing and closer well placement. Deeper contamination requires higher operating pressures and greater well spacing; therefore, depending on the site geology, fewer wells can be used, which will lower capital costs. Cost estimates for this technology range from about $50 to $300 per cubic yard, depending on the site characteristics. A recent study of six phase heating yielded a unit cost of $32 per cubic yard.

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Treatment Experiences at RCRA Corrective Actions, December 2000, EPA 542-F-00-020

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

California Base Closure Environmental Committee (CBCEC), 1994. *Treatment Technologies Applications Matrix for Base Closure Activities, Revision 1*, Technology Matching Process Action Team, November, 1994.

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.

EPA, 1997. *How Heat Can Enhance In situ Soil and Aquifer Remediation*, EPA/540/S-97/502.

EPA, 1997. *Steam Injection for Soil and Aquifer Remediation*, EPA/540/S-97/505.

Federal Remediation Technologies Roundtable, 1995. *Remediation Case Studies: Groundwater Treatment, Federal Remediation Technologies Roundtable*, EPA/542/R-95/003.

- Dynamic Underground Stripping Demonstration at DOE's Lawrence Livermore National Laboratory, Gasoline Spill Site, Livermore, California

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: In Situ Soil Treatment Technologies (Soil Vapor Extraction, Thermal Processes)*, EPA/542/R-98/012

- Contained Recovery of Oily Waste (CROW)™ Process at the Brodhead Creek Superfund Site, Stroudsburg, Pennsylvania

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Innovative Groundwater Treatment Technologies*, EPA/542/R-98/015.

- Dual Auger Rotary Steam Stripping at DOE's Pinellas Northeast Site, Largo, Florida

TOP

Site Information:

- Airfield, Lemoore, CA
- EPA Demo Huntington Beach, CA
- EPA SITE demo Pennsylvania Power & Light, Stroudsburg, PA
- Lawrence Livermore National Laboratory Gasoline Spill Site, Livermore, CA
- Brodhead Creek Superfund Site, Stroudsburg, PA
- DOE's Pinellas Northeast Site, Largo, FL
- Additional site information on the FRTR web site

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Site:

Government Web Sites

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Vendor Information:

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A list of vendors offering In Situ Physical/Chemical Water Treatment is available from EPA REACH

IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Ground Water, Surface Water, and Leachate >>3.10 In Situ Physical/Chemical Treatment >>4.38 Hydrofracturing

Introduction>> Injection of pressurized water through wells cracks low permeability and over-consolidated sediments. Cracks are filled with porous media that serve as substrates for bioremediation or to improve pumping efficiency.

Description:

Figure 4-38:
Typical Sequence of Operations for Creating Hydraulic Fractures

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.

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 or a similar substitute 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, substrates and nutrients for in situ bioremediation applications.

TOP

Synonyms:

DSERTS Code: F17 (Hydrofracturing - enhancement)

TOP

Applicability:

Hydrofracturing is applicable to a wide range of contaminant groups with no particular target group.

TOP

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.
- There is an inability to control the final location or size of the fractures that are created.
- Fractures are anticipated to collapse due to over burden pressure.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2. (Data Requirements for Ground Water, Surface Water, and Leachate).

TOP

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.

TOP

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.

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

EPA, 1991. *Feasibility of Hydraulic Fracturing of Soil to Improve Remedial Actions*, EPA/600/S2-91/012.

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93/505; and Technology Demonstration Summary, EPA/540/SR-93/505.

EPA, 1994. *In Situ Remediation Technology Status Report: Hydrofracturing/Pneumatic Fracturing,* EPA/542/K-94/005.

EPA, 1997. *Analysis of Selected Enhancements for Soil Vapor Extraction*, EPA OSWER, EPA/542/R-97/007.

Federal Remediation Technologies Roundtable, 1997. *Remediation Case Studies: Soil Vapor Extraction and Other In Situ Technologies*, EPA/542/R-97/009.

- Hydraulic and Pneumatic Fracturing at the U.S. Department of Energy's Portsmouth Gaseous Diffusion Plant, Ohio; Department of Defense; and Commercial Sites.

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.

TOP

Site Information:

- Xerox Facility Oak Brook, IL
- UST site, Dayton, OH
- DOE's Portsmouth Gaseous Diffusion Plant, OH

Points of Contact:

TOP

General FRTR Agency Contacts

Technology Specific Web Sites:

Non Government Web Sites

Vendor Information:

TOP

A list of vendors offering In Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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To be added

TOP

Technology>> Ground Water, Surface Water, and Leachate
>>3.10 In Situ Physical/Chemical Treatment
>>4.39 In-Well Air Stripping

Introduction>> Air is injected into a double screened well, lifting the water in the well and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. Once in the well, some of the VOCs in the contaminated ground water are transferred from the dissolved phase to the vapor phase by air bubbles. The contaminated air rises in the well to the water surface where vapors are drawn off and treated by a soil vapor extraction system.

Description:

Figure 4-39a:
Typical UVB Vacuum Vapor Extraction Diagram

Figure 4-39b:
Typical NoVOCs™ system

Figure 4-39c:
Typical DDC system

In-well air stripping technology air is injected into a vertical well that has been screened at two depths. The lower screen is set in the groundwater saturated zone, and the upper screen is in the unsaturated zone, often called as vadose zone. Pressurized air is injected into the well below the water table, aerating the water. The aerated water rises in the well and flows out of the system at the upper screen. Contaminated groundwater is drawn into the system at the lower screen. The volatile organic compounds (VOCs) vaporize within the well at the top of the water table, as the air bubbles out of the water. The vapors are drawn off by a soil vapor extraction (SVE) system. The partially treated ground water is never brought to the surface; it is forced into the unsaturated zone, and the process is repeated as water follows a hydraulic circulation pattern or cell that allows continuous cycling of ground water. As ground water circulates through the treatment system *in situ*, contaminant concentrations are gradually reduced. In-well air stripping is a pilot-scale technology.

Modifications to the basic in-well stripping process may involve additives injected into the stripping well to enhance biodegradation (e.g., nutrients, electron acceptors, etc.). In addition, the area around the well affected by the circulation cell (radius of influence) can be modified through the addition of certain chemicals to allow in situ stabilization of metals originally dissolved in ground water.

The duration of in-well air stripping is short- to long-term, depending contaminant concentrations, Henry's law constants of the contaminants, the radius of influence, and site hydrogeology.

➢ *Circulating Wells*

Circulating wells (CWs) provide a technique for subsurface remediation by creating a three-dimensional circulation pattern of the ground water. Ground Water is drawn into a well through one screened section and is pumped through the well to a second screened section where it is reintroduced to the aquifer. The flow direction through the well can be specified as either upward or downward to accommodate site-specific conditions. Because ground water is not pumped above ground, pumping costs and permitting issues are reduced and eliminated, respectively. Also, the problems associated with storage and discharge are removed. In addition to ground water

treatment, CW systems can provide simultaneous vadose zone treatment in the form of bioventing or soil vapor extraction.

CW systems can provide treatment inside the well, in the aquifer, or a combination of both. For effective in-well treatment, the contaminants must be adequately soluble and mobile so they can be transported by the circulating ground water. Because CW systems provide a wide range of treatment options, they provide some degree of flexibility to a remediation effort.

TOP

Synonyms:

Vacuum vapor extraction; In-well aeration; Vacuum vaporizer well; ground water circulating wells.

TOP

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. Typically, in-well air stripping systems are a cost-effective approach for remediating VOC-contaminated ground water at sites with deep water tables because the water does not need to be brought to the surface.

CW systems are most effective at treating sites with volatile contaminants with relatively high aqueous solubility and strong biodegradation potential, e.g., halogenated and non-halogenated VOCs. CWs operate more efficiently with horizontal conductivities greater that 10^{-3} cm/sec and a ratio of horizontal to vertical conductivities between 3 and 10. A ratio of less than 3 indicates short circulation times and a small radius of influence. If the ratio is greater that 10, the circulation time may be unacceptably long.

TOP

Limitations:

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

- UVB-type systems only treat the water in the stripping well.
- In general, in-well air strippers are more effective at sites containing high concentrations of dissolved contaminants with high Henry's law constants.
- Fouling of the system may occur by infiltrating precipatation containing oxidized constituents.
- Shallow aquifers may limit process effectiveness.
- Effective CW installations require a well-defined contaminant plume to prevent the spreading or smearing of the contamination. They should not be applied to sites containing NAPLs to prevent the possibility of smearing the contaminants.
- CWs are limited to sites with horizontal hydraulic conductivities greater that 10^{-5} cm/sec and should not be utilized at sites that have lenses of low-conductivity deposits.
- In well air stripping may not be efficient in sites with strong natural flow patterns.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, Surface Water, and Leachate).

TOP

Performance Data:

A variation of this process, called Unterdruck-Verdampfer Brunner (UVB), 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, called NoVOCs, 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. Wasatch Environmental, Inc. has also developed and patented another type of in-well vapor stripping system known as Denstiy Driven Convection (DDC). The DDC system emphasizes the enhancement of bioremediation and involves the dishcharge of extracted vapors into the vadose zone for degradation by naturally-occurring microorganisms. 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.

TOP

Cost:

Not available.

TOP

References:

Treatment Technologies for Site Cleanup: Annual Status Report (ASR), Tenth Edition, EPA 542-R-01-004

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

Melinda A. Trizinsky, 1999. Groundwater Circulating Wells with In-Well Air-Stripping: Despite drawbacks, in situ technology holds promise.

Miller, R. R. and Diane D.S., 1997. *Technology Overview Report: In-well Vapor Stripping*, GWRTAC Series TO-97-01.00

DOE, 1994. *Technology Catalogue*, First Edition. February.

TOP

Site Information:

- Fuel Dispensing Area 1595, Watertwon, NY
- Lawrence Livermore National Laboratory
- Site Demo March AFB, CA
- Savannah River Site, GA 1994
- NEL Demo: NAS North Island Installation Restoration (IR) Site 9, CA
- Additional Site Information on the FRTR web site

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

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Vendor Information:

A list of vendors offering In Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Ground Water, Surface Water, and Leachate >>3.10 In Situ Physical/Chemical Treatment >>4.40 Passive/Reactive Treatment Walls

Introduction>> These barriers allow the passage of water while causing the degradation or removal of contaminants.

Description:

Figure 4-40:
Typical Passive Treatment Wall (Cross-Section)

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 zero-valent metals, chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and others.

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.

➢ *Funnel and Gate*

Modifications to the basic passive treatment walls may involve a funnel-and-gate system or an iron treatment wall. The funnel-and-gate system for in situ treatment of contaminated plumes consists of low hydraulic conductivity (e.g., 1E-6 cm/s) cutoff walls (the funnel) with a gate that contains in situ reaction zones. Ground water primarily flows through high conductivity gaps (the gates). The type of cutoff walls most likely to be used in the current practice are slurry walls or sheet piles. Innovative methods such as deep soil mixing and jet grouting are also being considered for funnel walls.

➢ *Iron Treatment Wall*

An iron treatment wall consists of iron granules or other iron bearing minerals for the treatment of chlorinated contaminants such as TCE, DCE, and VC. As the iron is oxidized, a chlorine atom is removed from the compound by one or more reductive dechlorination mechanisms, using electrons supplied by the oxidation of iron . The iron granules are dissolved by the process, but the metal disappears so slowly that the remediation barriers can be expected to remain effective for many years, possibly even decades.

Barrier and post-closure monitoring tests are being conducted by the USAF, U.S. Navy, and 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.

Passive treatment walls are generally intended for long-term operation to control migration of contaminants in ground water.

TOP

Synonyms:

Permeable reactive barrier walls; In place bioreaction; In-situ chemical filters.
DSERTS Code: F16 (Passive Treatment Walls)

TOP

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.

TOP

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.
- Passive treatment wall permeability may decrease due to precipitation of metal salts.
- Depth and width of barrier.
- Limited to a subsurface lithology that has a continous aquitard at a depth that is within the vertical limits of trenching equipment.
- Volume cost of treatment medium.
- Biological activity or chemical precipitation may limit the permeability of the passive treatment wall.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2. (Data Requirements for Ground Water, Surface Water, and Leachate).

Data needs include hydraulic gradient; contaminant characteristics (depth, areal extent, type, and concentration); depth to ground water, including range of anticipated fluctuations; depth to impermeable barrier key-in; site stratigraphy; ground water hydrology; water quality, flow rate, and direction; soil permeability; and buffering capacity.

TOP

Performance Data:

Data has been developed by the USAF, the University of Waterloo, and Enviromental Technologies, Inc.

Several full-scale and demonstration scale walls have been installed for remediation of ground water contaminated with chlorinated aliphatic hydrocarbons. These sites include Lowry AFB and Moffett Field NAS. Several more sites are currently being evaluated or have passive treatment walls scheduled for installation.

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Economy of Scale

- Quantity of material treated has a large impact
- Width of the plume to be treated

- Choice of supplemental amendments
- Additional monitoring required by regulators

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply passive/reactive treatment wall technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

GW TECHNOLOGY:	Passive-Reactive Treatment Walls			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER CUBIC FOOT (of Treatment Wall)	$36	$48	$43	$73
COST PER CUBIC METER (of Treatment Wall)	$1,267	$1,681	$1,503	$2,580
COST PER CUBIC YARD (of Treatment Wall)	**$963**	**$1,277**	**$1,142**	**$1,961**
GW Treated (CY)	680,250	680,250	17,006,250	17,006,250
COST PER CUBIC YARD (of GW Treated)	**$0.16**	**$0.21**	**$0.08**	**$0.13**

Detailed Cost Estimate

TOP

References:

Technical Documents from the Remediation Technologies Development Forum (RTDF) Web Site which includes Installation Profiles and Field Applications of Permeable Reactive Barrier Walls.

California Base Closure Environmental Committee (CBCEC), 1994. *Treatment Technologies Applications Matrix for Base Closure Activities, Revision 1*, Technology Matching Process Action Team, November, 1994.

EPA, 1995. *In Situ Remediation Technology Status Report: Treatment Walls,* Office of Solid Waste and Emergency Response, EPA/540/K-94/004.

EPA, 1997. *Permeable Reactive Subsurface Barriers for the Interception and remediation of Chlorinated Hydrocarbon and Chromium(VI) Plumes in Ground Water,* EPA/600/F-97/008.

DOE, 1993. *Technical Name: Barriers and Post-Closure Monitoring,* Technology Information Profile (Rev. 2), DOE Protech Database, TTP No. AL-1211-25.

DOE, 1994. *Technology Catalogue*, First Edition. February.

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Innovative Groundwater Treatment Technologies*, EPA/542/R-98/015.

- Pump and Treat and Permeable Reactive Barrier to Treat Contaminated Groundwater at the Former Intersil, Inc. Site, Sunnyvale, California
- Permeable Reactive Barrier to Treat Contaminated Groundwater at Moffett Federal Airfield, Mountain

View, California
- In Situ Permeable Reactive Barrier for Treatment of Contaminated Groundwater at the U.S. Coast Guard Support Center, Elizabeth City, North Carolina

Hansen, W., et al., 1992. "Barriers and Post-Closure Monitoring", Briefing Chart, Los Alamos National Laboratory, Los Alamos, NM, TTP No. AL-1212-25.

USAF, 1997. *Design Guidance for Application of Permeable Barriers to Remediate Dissolved Chlorinated Solvents*, prepared by Battelle under contract to Environics Directorate, Armstrong Laboratory.

Vidic, R.D. and F.G. Pohland. "Technology Evaluation Report: Treatment Walls", GWRTAC Series TE-96-01.

TOP

Site Information:

- Tonolli Corporation, PA
- Lowry Air Force Base, CO
- Somersworth Sanitary Landfill Site, NH
- Moffett Field NAS, CA
- Brown's Battery Breaking Site, OU 2, PA
- Canadian Forces Base, Canada
- Borden Aquifer, Canada
- Air Force Demo Hill AFB, UT
- Los Alamos National Laboratory
- Former Intersil, Inc. Site, Sunnyvale, CA
- Moffett Federal Airfield, Mountain View, CA
- The U.S. Coast Guard Support Center, Elizabeth City, NC
- Additional site information on the FRTR web site

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A list of vendors offering In Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Ground Water, Surface Water, and Leachate >>3.11 Ex Situ Biological Treatment (assuming pumping) >>4.41 Bioreactors

Introduction>> Contaminants in extracted ground water are put into contact with microorganisms in attached or suspended growth biological reactors. In suspended systems, such as activated sludge, contaminated ground water 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.

Description:

Figure 4-41:
Typical Rotating Biological Contactor (RBC)

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 ground water 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. 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.

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.

Nutrients are often added to the bioreactors to support the growth of microorganisms.

Bioreactors are a long-term technology. The process may take up to several years.

➢ *Trickling Filter*

Another aerating wastewater treatment is the trickling filter. The trickling filter consists of a bed of highly permeable media, a water distributor, and an underdrain system. Wastewater is distributed over the top of the filter bed through which wastewater is trickled. The organic contaminants in wastewater are degraded by the microorganisms attached to the filter medium. The filter media may be rocks, plastic, or wood. The filter bed is normally round with depth varying from 3 to 8 ft (0.9 to 0.5m) and average 6 ft (1.8m). As wastewater flows over the solid filter media, it is aerated and the organic contaminants are degraded by the microorganisms attached to the media surface. The underdrain system is used to collect the treated water and any biomass detached from the filter media. It is also important as a porous structure through which air can circulate.

The duration of operation and maintenance of sprinkler irrigation depends on the amount of time needed to capture and treat the contaminated waste; monitoring of treated water; and monitoring of potential metal accumulation.

TOP

Synonyms:

Rotating Biological Reactor; Rotating Biological Contactors (RBC).
DSERTS Code: F18 (Bioreactors - Ex Situ)

TOP

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, chlorobenzene and dichlorobenzene isomers. Bioreactors with cometabolites are used to treat PCBs, halogenated VOCs, and SVOCs in extracted ground water.

TOP

Limitations:

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

- The dilute nature of contaminated ground water often will not support an adequate microbial population density, and this is especial true for suspended growth reactors. Nutrient addition may be necessary.
- Very high contaminant concentrations may be toxic to microorganisms and require special design approaches.
- 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.
- Residuals from sludge processes require treatment or disposal.
- Discharge of treated effluents may still be regulated.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, Surface Water, and Leachate).

Data requirements include contaminants and their concentrations, pH, presence of compounds toxic to microorganisms, contaminant biodegradability, BOD_5, COD, suspended solids, flow rate, temperature, and nutrient concentrations.

TOP

Performance Data:

This is a well developed technology that has been used for many decades in the treatment of municipal and industrial wastewater. However, only in the past decade, studies have been performed to evaluate the effectiveness of bioreactors in treating ground water and leachate from hazardous waste sites. Bioreactor 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.

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.

TOP

Cost:

The key cost driver information and cost analysis was developed using the 2006 version of the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Chemical Oxygen Demand (COD)
  - The COD a given waste exerts is the primary cost driver.
- pH Adjustment
  - The secondary cost driver is the amount of acid/base required to neutralize the pH of the waste stream.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply bioreactor technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

GW TECHNOLOGY:	Bioreactor			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
THOUSAND GALLONS TREATED	1,051	1,051	10,512	10,512
COST PER THOUSAND GALLONS	$143	$167	$21	$36

Detailed Cost Estimate

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Groundwater Cleanup: Overview of Operating Experience at 28 Sites, September 1999, EPA 542-R-99-006,

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

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.

DOE, 1994. *Technology Catalogue*, First Edition. February.

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.

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Site Information:

- DOI Demo Bureau of Mines
- EPA Demo MacGillis & Gibbs Superfund Site, MN
- DOI Demo Late Summer
- DOI Demo Bureau of Mines, NV
- DOI Demo Bureau of Mines, UT
- Navy Demo, Naval Weapons Station Seal Beach, CA
- EPA Demo St. Joseph, MI
- Air Force & DOE Demo Tinker AFB, OK
- Hanscomb AFB, MA
- Dow Chemical Site, TX
- Additional site information on the FRTR web site

Points of Contact:

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A list of vendors offering Ex Situ Biological Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Ground Water, Surface Water, and Leachate >>3.11 Ex Situ Biological Treatment (assuming pumping) >>4.42 Constructed Wetlands

Introduction>> The constructed wetlands-based treatment technology uses natural geochemical and biological processes inherent in an artificial wetland ecosystem to accumulate and remove metals, explosives, and other contaminants from influent waters. The process can use a filtration or degradation process.

Description:

Figure 4-42:
Typical Constructed Wetlands System

Although the technology incorporates principal components of wetland ecosystems; including organic soils, microbial fauna, algae, and vascular plants; microbial activity is responsible for most of the remediation.

Influent waters with high metal concentrations and low pH flow through the aerobic and anaerobic zones of the wetland ecosystem. Metals are removed through ion exchange, adsorption, absorption, and precipitation with geochemical and microbial oxidation and reduction. Ion exchange occurs as metals in the water contact humic or other organic substances in the wetland. Wetlands constructed for this purpose often have little or no soil instead they have straw, manure or compost. Oxidation and reduction reactions catalyzed by bacteria that occur in the aerobic and anaerobic zones, respectively, play a major role in precipitating metals as hydroxides and sulfides. Precipitated and adsorbed metals settle in quiescent ponds or are filtered out as water percolates through the medium or the plants.

Influent water with explosive residues or other contaminants flows through and beneath the gravel surface of a gravel-based wetland. The wetland, using emergent plants, is a coupled anaerobic-aerobic system. The anaerobic cell uses plants in concert with natural microbes to degrade the contaminant. The aerobic, also known as the reciprocating cell, further improves water quality through continued exposure to the plants and the movement of water between cell compartments.

Wetland treatment is a long-term technology intended to operate continously for years.

TOP

Synonyms:

NA

TOP

Applicability:

Constructed wetlands have most commonly been used in wastewater treatment for controlling organic matter; nutrients, such as nitrogen and phosphorus; and suspended sediments. The wetlands process is also suitable for controlling trace metals, and other toxic materials. Additionally,

the treatment has been used to treat acid mine drainage generated by metal or coal mining activities. These wastes typically contain high metals concentrations and are acidic. The process can be adapted to treat neutral and basic tailings solutions.

TOP

Limitations:

The wetlands remediation technology must be adjusted to account for differences in geology, terrain, trace metal composition, and climate in the metal mining regions of the western United States.

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

- The long-term effectiveness of constructed wetlands is not well known. Wetland aging may be a problem which may contribute to a decrease in contaminant removal rates over time.
- The cost of building an artificial wetland varies considerably from project and may not be financially viable for many sites.
- Temperature and fluctuations in flow affect wetland function and can cause a wetland to display inconsistent contaminant removal rates.
- Colder conditions slow the rate at which the wetland is able break down contaminants.
- A heavy flow of incoming water can overload the removal mechanisms in a wetland, while a dry spell can damage plants and severely limit wetland function.

TOP

Data Needs:

A detailed discussion of data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, Surface Water, and Leachate).

Performance Data:

This technology was accepted into the Emerging Technology Program in 1988; the project was completed in 1991. The purpose of the project was to build, operate, monitor, and assess the effectiveness of a constructed wetlands in treating a portion of acid mine drainage from the Big Five Tunnel site near Idaho Springs, Colorado. The Final Report (EPA/540/R-93/523) is available from NTIS (Order No. PB93-233914). The Summary (EPA/540/SR-93/523) and Bulletin (EPA/540/F-92/001) are available from EPA.

Study results indicated that heavy metal removal efficiency can approach the removal efficiency of chemical precipitation treatment plants. Some of the optimum results from the 3 years of operation are listed below.

- pH was raised from 2.9 to 6.5.
- Dissolved aluminum, cadmium, chromium, copper, and zinc concentrations were reduced by 99 percent or more.
- Iron was reduced by 99 percent.
- Lead was reduced by 94 percent or more.
- Nickel was reduced by 84 percent or more.
- Manganese removal was relatively low, with reduction between 9 and 44 percent.
- Biotoxicity to fathead minnows and water fleas was reduced by factors of 4 to 20.

Because wetland removal processes are primarily microbial, the technology can be developed with traditional process engineering approaches. Laboratory studies can indicate whether remediation is possible, while bench-scale experiments can determine the proper loading and reactor design. Using this approach, five laboratory proof-of-principle studies and three bench-scale studies have been performed, and at least four successful demonstration reactors have been built to remove heavy metals from different types of water.

A final project goal was to develop a manual that discusses design and operating criteria for constructing a full-scale wetland to treat acid mine discharges. The "Wetland Designs for Mining

Operations" manual is available from the National Technical Information Service.

Based on the results from the SITE Emerging Technology Program, this technology was selected to participate in the SITE Demonstration Technology Program. Under the Demonstration Program, EPA is evaluating the effectiveness of biogeochemical processes at the Burleigh Tunnel mine site, near Silver Plume, Colorado. Treatment of Burleigh Tunnel discharge is part of the remedy for the Clear Creek/Central City Superfund site. Construction of a pilot-scale system began in summer 1993 and was completed in October 1993. For more information on this project, refer to the Colorado Department of Health profile in the Demonstration Program section (ongoing projects).

The USAEC is demonstrating a gravel based wetland system at Milan Army Ammunition Plant through the ESTCP. The gravel-based system has been effective at degrading TNT and RDX, with a total nitrobody concentration of 10,000 ppb. Analyses indicate degradation due to the rise and fall of daughter products. TNT is reduced to less than 2 ppb. The demonstration had been operational since June 1996.

TOP

Cost:

Studies at Milan Army Ammunition Plant conducted by USAEC and Tennessee Valley Authority (TVA) indicate that plants with nitroreductase, in concert with microbes, can degrade explosive residues. It is estimated that amortizing the capital costs of wetland treatment over a 10 year period results in a cost of $1.36/Kgal; over a 30 years period, the cost is $0.45/Kgal.

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

Constructed Wetlands: Passive Systems for Wastewater Treatment, August 2001, Technology Status Report prepared for the US EPA Technology Innovation Office

EPA, 1993. *Constructed Wetlands-Based Treatment*, EPA/540/R-93/523.

EPA, 1995. *Colorado School of Mines profile in the Emerging Technology Program.*

Lefave, J.P., 1997. *Constructed Wetlands for Treatment of NPS Pollution*, NFESC.

TOP

Site Information:

- Burleigh Tunnel Silver Plume, CO
- EPA Demo Burleigh Tunnel, CO
- Big Five Tunnel, CO
- Bear Creek, Oak Ridge, TN
- Naval Amphibious Base in Little Creek, Virginia

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Government Disclaimer

Health and Safety:

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To be added

TOP

Technology>> Ground Water, Surface Water, and Leachate >>3.12 Ex Situ Physical/Chemical Treatment >>4.43 Adsorption/Absorption

Introduction>> In liquid adsorption, solutes concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase.

Description:

Figure 4-43: Typical Adsorption/Absorption System

Adsorption mechanisms are generally categorized as either physical adsorption, chemisorption, or electrostatic adsorption. Weak molecular forces, such as Van der Waals forces, provide the driving force for physical adsorption, while a chemical reaction forms a chemical bond between the compound and the surface of the solid in chemisorption. Electrostatic adsorption involves the adsorption of ions through Coulombic forces, and is normally referred to as ion exchange, which is addressed separately in the ion exchange modules. In liquids, interactions between the solute and the solvent also play an important role in establishing the degree of adsorption.

The most common adsorbent is granulated activated carbon (GAC) (Technology Profile No. 4.46). Other natural and synthetic adsorbents include: activated alumina, forage sponge, lignin adsorption, sorption clays, and synthetic resins.

➢ *Activated Alumina*

Activated alumina is a filter media made by treating aluminum ore so that it becomes porous and highly adsorptive. Activated alumina will remove variety of contaminants, including excessive fluoride, arsenic, and selenium. The medium requires periodic cleaning with an appropriate regenerant such as alum or acid in order to remain effective.

➢ *Forage Sponge*

Forage sponge is an open-celled cellulose sponge incorporating an amine-containing chelating polymer that selectively absorbs dissolved heavy metals. The polymer is intimately bonded to the cellulose so as to minimize physical separation from the supporting matrix. The functional groups in the polymer (i.e. amine and carboxyl groups) provide selective affinity for heavy metals in both cationic and anionic states, preferentially forming complexes with transition-group heavy metals.

➢ *Lignin Adsorption/Sorptive Clay*

Lignin adsorption/sorptive clays are used to treat aqueous waste streams with organic, inorganic and heavy metals contamination. The waste stream is treated due to the molecular adhesion of the contaminants to an adsorptive surface.

➢ *Synthetic Resins*

Synthetic resins are more expensive than GAC, but can be designed to achieve higher degrees of

selectivity and adsorption capacity for certain compounds than activated carbon. Resins are typically regenerated using acids, bases, or organic solvents, instead of thermal methods, so they are better suited for thermally unstable compounds such as explosives, and are resistant to deactivation due to the adsorption of dissolved solids. Additionally, resins tend to be more resistant to abrasion than activated carbon, increasing their service life.

TOP

Synonyms:

Liquid phase adsorption.

TOP

Applicability:

The target contaminants groups for adsorption/absorption processes are most organic contaminants and selected inorganic contaminants from liquid and gas streams. Activated alumina can remove fluoride and heavy metals. The forager sponge is specifically used to remove heavy metals. Lignin adsorption/sorptive clays treat organic, inorganic and heavy metals contamination within aqueous waste streams. Synthetic resins are better suited for thermally unstable compounds such as explosives than GAC, due to the resins' non-thermal regeneration requirements.

TOP

Limitations:

Factors that may limit the applicability and effectiveness of these processes include:

- Water-soluble compounds and small molecules are not adsorbed well.
- Costs are high if used as the primary treatment on waste streams with high contaminant concentration levels.
- Not applicable to sites having high levels of oily substances.
- Not practical where the content of the absorbable hazardous substance is so high that very frequent replacement of the absorbent unit is necessary.
- Contaminated media often require treatment/disposal as hazardous wastes, if they can't be regenerated.

TOP

Data Needs:

A detailed discussion of data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, Surface Water, and Leachate).

TOP

Performance Data:

Adsorption/absorption processes have a long history of use as treatment for municipal, industrial, and hazardous waste streams. The concepts, theory, and engineering aspects of the technologies are well developed. They are proven technologies with documented performance data.

TOP

Cost:

The cost to treat heavy metal contaminated ground water over a one year period with the Forager Sponge technology is estimated at $340/1000 gallons, assuming the sponges are not regenerated and are replaced upon saturation; or $238/1000 gallons, assuming the sponges are regenerated twice providing for three useful treatment cycles. Costs for other adsorbent processes are not

available.

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References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June, 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

MTBE Treatment Case Studies presented by the USEPA Office of Underground Storage Tanks.

Batteile Memorial Institute, 1995. "ReOpt V3.1 User Documentation", for DOE under contract DE/AC06/76RLO 1830.

Rainer, N., 1995. "Forager Sponge, Technology Description", Dynaphone, Inc.

Water Quality Association, 1994. "Treating the Water We Drink, When and Where We Drink It.", *WaterReview Technical Brief*, Vol. 9, No. 4.

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Site Information:

- EPA Demo National Lead Industry, NJ
- Pease Air Force Base, Newington, NH
- Superfund Site: Western Processing, WA
- Superfund Site: Rocky Mountain Arsenal, OU 17, CO
- Superfund Site: Vally Wood Preserving, Inc., Turlock, CA
- Superfund Site: Motor Wheel, Lansing TWP, MI
- Superfund Site: Perham Arsenic, Perham, MN
- Additional site information on the FRTR web site

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Vendor Information:

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A list of vendors offering Ex Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Technology>> Ground Water, Surface Water, and Leachate >>3.12 Ex Situ Physical/Chemical Treatment (assuming pumping) >>4.44 Advanced Oxidation Processes

Introduction>> Advanced Oxidation Processes including ultraviolet (UV) radiation, ozone, and/or hydrogen peroxide are used to destroy organic contaminants as water flows into a treatment tank. If ozone is used as the oxidizer, an ozone destruction unit is used to treat collected off gases from the treatment tank and downstream units where ozone gas may collect, or escape.

Description:

Figure 4-44:
Typical UV/Oxidation Ground water Treatment System

UV oxidation is a destruction process that oxidizes organic and explosive constituents in wastewater by the addition of strong oxidizers and irradiation with UV light. Oxidation of target contaminants is caused by direct reaction with the oxidizers, UV photolysis, and 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.

The UV oxidation process is general done with low pressure lamps operating at 65 watts of electricity for ozone systems and lamps operating at 15kW to 60kW for hydrogen peroxide systems.

➢ *UV Photolysis*

UV photolysis is the process by which chemical bonds of the contaminants are broken under the influence of UV light. Products of photo-degradation vary according to the matrix in which the process occurs, but the complete conversion of an organic contaminant to CO_2, H_2O, etc. is not probable.

The duration of operation and maintenance of UV oxidation depends on influent water turbidity, contaminant and metal concentrations, existence of free radical scavengers, and the required maintenance intervals on UV reactors and quartz sleeves.

TOP

Synonyms:

DSERTS Code: F21 (UV Oxidation)

TOP

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.

TOP

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 more 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 oxidizers 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.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, Surface Water, and Leachate).

Design and operational parameters include contact or retention time, influent water turbidity, metals and contaminant concentrations, existence of free radical scavengers, oxidizer influent dosages, pH, temperature, UV lamp intensity, and performance characteristics of catalysts.

TOP

Performance Data:

The UV/oxidation is an innovative ground water treatment technology that has been used in full-scale ground water 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 ground water 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).

TOP

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.

TOP

References:

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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.

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Site Information:

- Tracey, CA
- Lawrence Livermore Site 300, CA
- EPA Demo Coleman-Evans Site, FL
- Navy Demo Bangor SUBASE, WA
- Navy Demo U.S. Navy Site, NJ
- Winthrop Superfund Site, ME
- Milan AAP Milan, TN
- Air Force & EPA Demo Edwards AFB, CA
- EPA Demo Lake Charles Treatment Center, LA
- EPA Demo San Jose, CA
- DOE Demo Kansas City Plant, MO
- Bofors Nobel Superfund Site, Muskegon, MI
- Additional site information on the FRTR web site

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Technology>> Ground Water, Surface Water, and Leachate >>3.12 Ex Situ Physical/Chemical Treatment (assuming pumping) >>4.45 Air Stripping

Introduction>> Volatile organics are partitioned from extracted ground water by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

Description:

Figure 4-45:
Typical Air Stripping System

Air stripping is a full-scale technology in which volatile organics are partitioned from ground water 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.

Air stripping involves the mass transfer of volatile contaminants from water to air. For ground water 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.

Modifying packing configurations greatly increase removal efficiency. A recent innovation is the so-called low-profile air stripper that is offered by several commercial vendors. This unit packs a number of trays in a very small chamber to maximize air-water contact while minimizing space. Because of the significant vertical and horizontal space savings, these units are increasingly being used for ground water 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.

The eventual duration of cleanup using an air stripping system may be tens of years and depends on the capture of the entire plume from the ground water.

TOP

Synonyms:

DSERTS Code: F19 (Air Stripping)

TOP

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.

TOP

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.
- Effective only for contaminated water with VOC or semivolatile concentrations with a dimensionless Henry's constant greater than 0.01.
- Consideration should be given to the type and amount of packing used in the tower
- Process energy costs are high..
- Compounds with low volatility at ambient temperature may require preheating of the ground water.
- Off-gases may require treatment based on mass emission rate.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, Surface Water, and Leachate).

Vendors require the following information to select the properly configured tower and packing 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.

TOP

Performance Data:

Removal efficiencies around 99% are typical for towers that have 4.6 to 6 meters (15 to 20 feet) of conventonal 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, or changing the configuration of packing material. 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 manganese, by precipitation of calcium, and by biological growth on the packing material.

TOP

Cost:

The key cost driver information and cost analysis was developed in 2006 using the Remedial Action Cost Engineering and Requirements (RACER) software.

Low Profile Tray Stacks

Key Cost Drivers

- Influent flow rate
- Relative contaminant volatility
- Off-gas treatment (when necessary)

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply ex situ air stripping using low profile tray stack technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

GW TECHNOLOGY:	Ex Situ Air Stripping--Low Profile Tray Stack			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
GALLONS TREATED	52,560,000	52,560,000	1,314,000,000	1,314,000,000
COST PER GALLON	$0.0020	$0.0021	$0.0004	$0.0004
COST PER 10,000 GALLONS	$20	$21	$4	$4

Detailed Cost Estimate

Packed Towers

Key Cost Drivers

- Influent flow rate
- Relative contaminant volatility
- Off-gas treatment (when necessary)

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply ex situ air stripping using packed tower technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

GW TECHNOLOGY:	Ex Situ Air Stripping--Packed Tower			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
GALLONS TREATED	52,560,000	52,560,000	1,314,000,000	1,314,000,000
COST PER GALLON	$0.0023	$0.0034	$0.0004	$0.0005
COST PER 10,000 GALLONS	$23	$34	$4	$5

Detailed Cost Estimate

A major operating cost of air strippers is the electricity required for the ground water pump, the sump discharge pump, and the air blower. The power rating of the ground water pump depends on the pressure head and pressure drop across the column and should be obtained from pump curves. As a general 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.

TOP

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- Pump and Treat of Contaminated Groundwater at the City Industries Superfund Site, Orlando, Florida

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Site Information:

- Englin AFB
- DOE - Savannah River Site, SC
- Langley AFB, VA
- McClellan AFB, CA
- Army Demo Fort Dix, NJ
- Verona Wellfield Battle Creek, MI
- City Industries Superfund Site, Orlando, FL
- Fort Drum, Fuel Dispensing Area 1595, Watertown, NY
- Additional site information on the FRTR web site

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Technology>> Ground Water, Surface Water, and Leachate >>3.12 Ex Situ Physical/Chemical Treatment (assuming pumping) >>4.46 Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption

Introduction>> Ground water 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.

Description:

Figure 4-46:
Typical Fixed-Bed Carbon Adsorption System

Liquid phase carbon adsorption is a full-scale technology in which ground water is pumped through one or more vessels containing activated carbon to which dissolved organic 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. Carbon used for explosives- or metals-contaminated ground water probably cannot be regenerated and should be removed and properly disposed. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes.

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. Pretreatment for removal of suspended solids from streams to be treated is an important design consideration. If not removed 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.

Modification of GAC, such as silicone impregnated carbon, could increase removal efficiency and extend the length of operation. It may also be safer to regenerate.

The duration of GAC is usually short-term; however, if concentrations are low enough, the duration may be long-term. The duration of operation and maintenance is dependent on contaminant type, concentration, and volume; regulatory cleanup requirements; and metal concentrations.

TOP

Synonyms:

Activated carbon; Carbon filtration.
DSERTS Code: F20 (Carbon Absorption)

TOP

Applicability:

The target contaminant groups for carbon adsorption are hydrocarbons, SVOCs and explosives. Limited effectiveness may be achieved on halogenated VOCs 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.

TOP

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.
- Streams with high suspended solids (> 50 mg/L) and oil and grease (> 10 mg/L) may cause fouling of the carbon and may require frequent treatment. In such cases, pretreatment is generally required.
- Costs are high if used as the primary treatment on wastestreams with high contaminant concentration levels.
- Type, pore size, and quality 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- or metals-contaminated ground water is not regenerated.
- Highly Water-soluble compounds and small molecules are not adsorbed well.
- All spent carbon eventually need to be properly disposed.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, 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 (ratio of effluent concentration,C_e, to influent concentration, C_o, <0.05), 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.

TOP

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.

TOP

Cost:

Costs associated with GAC are dependent on wastestream flow rates, type of contaminant, concentration of contaminant, mass loading, required effluent concentration, 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.

Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes (HTRW) Historical Cost Analysis System (HCAS) developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group.

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References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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- Petroleum Product Recovery and Contaminated Groundwater Remediation at Amoco Petroleum Pipeline, Constantine, Michigan
- Pump and Treat System at Commencement Bay, South Tacoma Channel (Well 12A), Phase 2, Tacoma, Washington
- Recovery of Free Petroleum Product at Fort Drum, Fuel Dispensing Area 1595, Watertown, New York

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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.

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Site Information:

- Verona Wellfield Battle Creek, MI
- U.S. Coast Guard Traverse City, MI
- Love Canal Niagara Falls, NY
- Milan AAP Milan, TN
- Fort Drum, Watertown, NY
- Amoco Petroleum Pipeline, Constantine, MI
- Commencement Bay, South Tacoma Channel (Well 12A), Phase 2, Tacoma, WA
- Fort Drum, Fuel Dispensing Area 1595, Watertown, NY

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Technology>> Ground Water, Surface Water, and Leachate
>>3.12 Ex Situ Physical/Chemical Treatment
>>4.47 Ground Water Pumping/Pump and Treat

Introduction>> Ground water pumping is a component of many pump-and-treat processes, which are some of the most commonly used ground water remediation technologies at contaminated sites.

Description:

Figure 4-47a:
Typical Ground Water Pumping System

Possible objectives of ground water pumping include removal of dissolved contaminants from the subsurface, and containment of contaminated ground water to prevent migration.

The first step of any remediation project consists of defining the remedial action objectives to be accomplished at the site. This involves gathering enough background site information and field data to make assessments of remedial requirements and possible cleanup levels. The first determination is whether cleanup or containment will be the most appropriate remedial action. If cleanup is chosen, the level of cleanup must be determined. If containment is chosen, ground water pumping is used as a hydraulic barrier to prevent off-site migration of contaminant plumes.

The next component consists of the design and implementation of the ground water pumping system based on data evaluated in setting the goals and objectives. The criteria for well design, pumping system, and treatment are dependent on the physical site characteristics and contaminant type. Actual treatment may include the design of a train of processes such as gravity segregation, air strippers, carbon systems tailored to remove specific contaminants.

Another component of any ground water extraction system is a ground water monitoring program to verify its effectiveness. Monitoring the remedial with wells and piezometers allows the operator to make iterative adjustments to the system in response to changes in subsurface conditions caused by the remediation.

The final component is determining the termination requirements. Termination requirements are based on the cleanup objectives defined in the initial stage of the remedial process. The termination criteria are also dependent on the specific site aspects revealed during remedial operations.

Although pumping for containment implies no treatment the following treatments usually follow pumping in pump and treat systems. These are briefly described below and in detail in technology profiles 4.41 through 4.51:

4.41 Bioreators:
Contaminants in extracted ground water are put into contact with microorganisms in attached or suspended growth biological reactors. In suspended systems, such as activated sludge, contaminated ground water 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.

4.42 Constructed wetlands:
The constructed wetlands-based treatment technology uses natural geochemical and biological processes inherent in an artificial wetland ecosystem to accumulate and remove metals and other contaminants from influent waters.

4.43 Adsorption/Absorption:
In liquid adsorption, solutes concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase. The most common adsorbent is granulated activated carbon (GAC) (see Technology Profile No. 4.51). Other natural and synthetic adsorbents include: forage sponge, lignin adsorption, sorption clays, and synthetic resins.

4.45 Air Stripping:
Volatile organics are partitioned from ground water by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

4.46 Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption:
Ground water 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.

4.48 Ion Exchange:
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.

4.49 Precipitation/Coagulation/ Flocculation:
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.

4.50 Separation:
Separation processes seek to detach contaminants from their medium (i.e., ground water and/or binding material that contain them). Ex situ separation of waste stream can be performed by many processes: (1) distillation, (2) filtration/ultrafiltration/microfiltration, (3) freeze crystallization, (4) membrane pervaporation and (5) reverse osmosis.

4.51 Sprinkler Irrigation:
Wastewater is distributed over the top of the filter bed through which wastewater is trickled. The organic contaminants in wastewater are degraded by the microorganisms attached to the filter medium.

➢ *Surfactant Enhanced Recovery*

The application of surfactants micelles or steam to the ground water can facilitate the ground water pumping process by increasing the mobility and solubility of the contaminants sorbed to the soil matrix. This material can also facilitate the entrainment of hydrophobic contaminants to allow removal and assures that multi-phase contaminants can be effectively removed. Thus it can increase the contaminant mass removal per pore volume of ground water flushing through the contaminated zone.

The implementation of surfactant-enhanced recovery requires the injection of surfactants into a contaminated aquifer. Typical systems utilize a pump to extract ground water at some distance away from the injection point. The extracted ground water is treated ex situ to separate the injected surfactants from the contaminants and ground water. In order to be cost-effective, the design of the surfactant-enhanced recovery system is critical. Once the surfactants have separated from the ground water they can be re-injected into the subsurface. Contaminants must be separated from the ground water and treated prior to discharge of the extracted ground water.

➢ *Drawdown Pumping*

Pump drawdown nonaqueous-phase liquid (NAPL) recovery systems are designed to pump NAPL and ground water from recovery wells or trenches. Pumping removes water and lowers the water table near the extraction area to create a cone of depression. The cone of depression in the vicinity of the extraction well produces a gravity head that pushes flow of NAPL toward the well and increases the thickness of the NAPL layer in the well. Each foot of ground water depression provides a driving head equivalent to a pressure difference of 0.45 psi. In most cases, the production of a cone of depression will increase NAPL recovery rates.

Pumping may be accomplished with one or two pumps. In the single-pump configuration, one pump withdraws both water and NAPL. The dual-pump configuration uses one pump located below the water table to remove water and a second located in the NAPL layer to recover NAPL. A single-pump system reduces capital and operating costs and allows simpler control systems and operation, but produces a stream of mixed water and NAPL that must then be separated.

The Dual Phase Extraction (DPE) process for undissolved liquid-phase organics, also known as free product recovery, 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. Dual phase extraction is a full-scale technology.

Figure 4-47b:
Typical Free Product Recovery Dual Pump System

TOP

Synonyms:

Pump and treat.
DSERTS Code: Q1 (Waste Removal - Liquids)

TOP

Applicability:

The first step in determining whether ground water pumping is an appropriate remedial technology is to conduct a site characterization investigation. Site characteristics, such as hydraulic conductivity, will determine the range of remedial options possible. Chemical properties of the site and plume need to be determined to characterize transport of the contaminant and evaluate the feasibility of ground water pumping. To determine if ground water pumping is appropriate for a site, one needs to know the history of the contamination event, the properties of the subsurface, and the biological and chemical contaminant characteristics. Identifying the chemical and physical site characteristics, locating the ground water contaminant plume in three dimensions, and determining aquifer and soil properties are necessary in designing an effective ground water pumping strategy.

Surfactant-enhanced recovery are most applicable for contaminated sites with enhanced dense, nonaqueous-phase liquids (DNAPLs).

Drawdown pumping is effective for NAPL recovery when the aquifer has moderate to high hydraulic conductivity and a thick layer of low-viscosity NAPL. An aquifer with high hydraulic conductivity gives less flow resistance of NAPL into the well. A thick layer of NAPL allows the pumping system to collect a high proportion of NAPL in relation to the amount of ground water. For best operation, the NAPL thickness should be sufficient to completely cover the pump suction port.

Drawdown pumping is a commercially available technology that can be easily implemented with conventional pumps in wells or trenches. System installation costs are low to moderate, but the cost per amount of NAPL recovered varies greatly.

TOP

Limitations:

The following factors may limit the applicability and effectiveness of ground water pumping as part of the remedial process:

- The potentially long time necessary to achieve the remediation goal
- System designs fail to contain the contaminant as predicted, allowing the plume to migrate and failure of the pumping equipment.
- Residual saturation of the contaminant in the soil pores cannot be removed by ground water pumping. Contaminants tend to be sorbed in the soil matrix. Ground water pumping is not applicable to contaminants with high residual saturation, contaminants with high sorption capabilities, and homogeneous aquifers with hydraulic conductivity less than 10^{-5} cm/sec.
- The cost of permitting procuring and operating treatment systems is high. Additional cost may also be attributed to the disposal of spend carbon and other treatment residuals and wastes.
- Biofouling of the extraction wells and associated treatment stream is a common problem which can severely affect system performance. The potential for this problem should be evaluated prior to the installation.

The following factors may limit the applicability and effectiveness of surfactant-enhanced recovery:

- Subsurface heterogeneities, as with most ground water remediation technologies, present challenges to the successful implementation of surfactant-enhanced recovery
- Potential toxic effects of residual surfactants in the subsurface
- Off-site migration of contaminants due to the increase solubility achieved with surfactant injection Obtaining regulatory approval to inject surfactants into an aquifer.

The following factors may limit the applicability and effectiveness of drawdown pumping:

- Drawdown pumping generally produces large volumes of water in the process of recovering the free product.
- The production of a cone depression in the water table can smear the free product or trap the fuel in the saturated zone when the water table returns to its original level.

TOP

Data Needs:

Collecting as much background site data as possible, obtaining accurate information on the type of contaminants present, and determining the hydrogeological nature of the site are essential. Contaminant information needed consists of: 1) source characterization, including the volume released, the area infiltrated, and duration of release; 2) concentration distribution of contaminants and naturally occurring chemicals in the ground water and soil; and 3) processes affecting plume development, such as chemical and biological reactions influencing contaminant mobility. Hydrogeologic information include determining the size of the contaminated aquifer, depth to water table, hydraulic conductivity of the surrounding aquifer material, impermeable units and confining layers, ground water flow direction and velocity, recharge and discharge areas, seasonal variations of ground water conditions, and local ground water use. Methods for determining aquifer properties include a slug test, pump test, and a borehole flowmeter test. The pump test consists of pumping one well and measuring the water level response of surrounding wells. A slug test measures the rate at which water level in one well returns to its initial state after inducing a rapid water level change by introducing or with drawing a volume of water. The borehole flowmeter test measures flow direction and rate in a borehole.

TOP

Performance Data:

DOE has developed and tested many pump and treat technologies for hazardous waste removal over the past twenty years. Performance data on some of the most recent DOE sites can be in the Technology Application Analyses and site information below.

TOP

Cost:

Cost data varies from site to site for ground water pump and treat technology. Recent cost data on a few of DOE's sites can be found below in the links to the Technology Application Analyses and in the site information.

Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes (HTRW) Historical Cost Analysis System (HCAS) developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group.

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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- Recovery of Free Petroleum Product at Fort Drum, Fuel Dispensing Area 1595, Watertown, New York
- Pump and Treat of Contaminated Groundwater at IRP Site 4, Langley Air Force Base, Virginia
- Pump and Treat of Contaminated Groundwater at Operable Unit B/C, McClellan Air Force Base, California
- Pump and Treat of Contaminated Groundwater at the Twin Cities Army Ammunition Plant, New Brighton, Minnesota
- Pump and Treat of Contaminated Groundwater at the U.S. Department of Energy's Kansas City Plant, Kansas City, Missouri
- Pump and Treat of Contaminated Groundwater at the U.S. Department of Energy's Savannah River Site, A/M Area, Aiken, South Carolina

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Groundwater Pump and Treat (Chlorinated Solvents),* EPA/542/R-98/013

- Pump and Treat of Contaminated Groundwater at the Des Moines TCE Superfund Site, OU 1, Des Moines, Iowa
- Pump and Treat of Contaminated Groundwater at the Former Firestone Facility Superfund Site, Salinas, California
- Pump and Treat of Contaminated Groundwater at the JMT Facility RCRA Site, Brockport, New York
- Pump and Treat of Contaminated Groundwater at the Keefe Environmental Services Superfund Site, Epping, New Hampshire
- Groundwater Pump and Treat and Soil Vapor Extraction at DOE's Lawrence Livermore National Laboratory, Site 300, GSA OU, Livermore, California
- Pump and Treat of Contaminated Groundwater at the Mystery Bridge at Hwy 20 Superfund Site, Dow/DSI Facility, Evansville, Wyoming
- Groundwater Containment at Site LF-12, Offutt AFB, Nebraska
- Pump and Treat of Contaminated Groundwater at the Old Mill Superfund Site, Rock Creek, Ohio
- Pump and Treat of Contaminated Groundwater at the SCRDI Dixiana Superfund Site, Cayce, South Carolina
- Groundwater Containment at Site OT-16B, Shaw AFB, South Carolina

- Groundwater Containment at Site SD-29 and ST-30, Shaw AFB, South Carolina
- Pump and Treat of Contaminated Groundwater at the Sol Lynn/Industrial Transformers Superfund Site, Houston, Texas
- Pump and Treat of Contaminated Groundwater at the Solid State Circuits Superfund Site, Republic, Missouri
- Pump and Treat of Contaminated Groundwater with Containment Wall at the Solvent Recovery Services of New England, Inc. Superfund Site, Southington, Connecticut

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Groundwater Pump and Treat (Nonchlorinated Solvents)*, EPA/542/R-98/014

- Pump and Treat of Contaminated Groundwater at the Baird and McGuire Superfund Site, Holbrook, Massachusetts
- Pump and Treat of Contaminated Groundwater at the City Industries Superfund Site, Orlando, Florida
- Pump and Treat of Contaminated Groundwater at the King of Prussia Technical Corporation Superfund Site, Winslow Township, New Jersey
- Pump and Treat of Contaminated Groundwater at the LaSalle Electrical Superfund Site, LaSalle, Illinois
- Pump and Treat of Contaminated Groundwater at the Mid-South Wood Products Superfund Site, Mena, Arkansas
- Pump and Treat of Contaminated Groundwater at the Odessa Chromium I Superfund Site, OU 2, Odessa, Texas
- Pump and Treat of Contaminated Groundwater at the Odessa Chromium IIS Superfund Site, OU 2, Odessa, Texas
- Groundwater Containment at Site FT-01, Pope AFB, North Carolina
- Groundwater Containment at Site SS-07, Pope AFB, North Carolina
- Pump and Treat and Containment of Contaminated Groundwater at the Sylvester/Gilson Road Superfund Site, Nashua, New Hampshire
- Pump and Treat of Contaminated Groundwater at the United Chrome Superfund Site, Corvallis, Oregon
- Pump and Treat of Contaminated Groundwater at the U.S. Aviex Superfund Site, Niles, Michigan
- Pump and Treat of Contaminated Groundwater at the Western Processing Superfund Site, Kent, Washington

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- Pump and Treat and Permeable Reactive Barrier to Treat Contaminated Groundwater at the Former Intersil, Inc. Site, Sunnyvale, California
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- Pump and Treat and Air Sparging of Contaminated Groundwater at the Gold Coast Superfund Site, Miami, Florida
- Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the Libby Groundwater Superfund Site, Libby, Montana
- Pump and Treat, In Situ Bioremediation, and In Situ Air Sparging of Contaminated Groundwater at Site A, Long Island, New York

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Site Information:

- Lawerence Livermore Nat'l Lab (LLNL), Livermore, CA
- McClellan Air Force Base, Operable Unit (OU) D, CA
- FAA Technical Center, NJ
- Former Intersil, Inc. Site, Sunnyvale, CA
- Amoco Petroleum Pipeline, Constantine, MI
- Baird and McGuire Superfund Site, Holbrook, MA
- City Industries Superfund Site, Orlando, FL
- Commencement Bay, South Tacoma Channel (Well 12A), Phase 2, Tacoma, WA

- Des Moines TCE Superfund Site, OU 1, Des Moines, IO
- Former Firestone Facility Superfund Site, Salinas, CA
- Fort Drum, Fuel Dispensing Area 1595, Watertown, NY
- French Ltd. Superfund Site, Crosby, TX
- Gold Coast Superfund Site, Miami, FL
- JMT Facility RCRA Site, Brockport, NY
- Keefe Environmental Services Superfund Site, Epping, NH
- King of Prussia Technical Corporation Superfund Site, Winslow Township, NJ
- Langley Air Force Base, IRP Site 4, Langley, VA
- LaSalle Electrical Superfund Site, LaSalle, IL
- DOE's Lawrence Livermore National Laboratory, Site 300, GSA OU, Livermore, CA
- Libby Groundwater Superfund Site, Libby, MT
- McClellan Air Force Base, Operable Unit (OU) B/C,CA
- Mid-South Wood Products Superfund Site, Mena, AR
- Mystery Bridge at Hwy 20 Superfund Site, Dow/DSI Facility, Evansville, WY
- Odessa Chromium I Superfund Site, OU 2, Odessa, TX
- Odessa Chromium IIS Superfund Site, OU 2, Odessa, TX
- Site LF-12, Offutt AFB, NB
- Old Mill Superfund Site, Rock Creek, OH
- Site FT-01, Pope AFB, NC
- Site SS-07, Pope AFB, NC
- SCRDI Dixiana Superfund Site, Cayce, SC
- Site OT-16B, Shaw AFB, SC
- Site SD-29 and ST-30, Shaw AFB, SC
- Site A, Long Island, NY
- Sol Lynn/Industrial Transformers Superfund Site, Houston, TX
- Solid State Circuits Superfund Site, Republic, MO
- Solvent Recovery Services of New England, Inc. Superfund Site, Southington, CT
- Sylvester/Gilson Road Superfund Site, Nashua, NH
- Twin City Army Ammunition Plant, New Brighton, MN
- United Chrome Superfund Site, Corvallis, OR
- U.S. Aviex Superfund Site, Niles, MI
- U.S. DOE's Kansas City Plant, Kansas City, MO
- U.S. DOE's Savannah River Site A/M Area, Aiken, SC
- Western Processing Superfund Site, Kent, WA
- **Additional site information on the FRTR web site**

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A list of vendors offering Water Containment Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

Technology>> Ground Water, Surface Water, and Leachate >>3.12 Ex Situ Physical/Chemical Treatment (assuming pumping) >>4.48 Ion Exchange

Introduction>> Ion exchange removes ions from the aqueous phase by exchange with counter ions on the exchange medium.

Description:

Figure 4-48:
Typical Ion Exchange and Adsorption Equipment Diagram

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.

The duration of ion exchange technology is typically short- to medium-term depending on the factors discussed in Data Needs.

TOP

Synonyms:

NA

TOP

Applicability:

Ion exchange can remove dissolved metals and radionuclides from aqueous solutions. Other compounds that have been treated include nitrate, ammonia nitrogen, and silicate.

TOP

Limitations:

Factors that may affect the applicability and effectiveness of this process include:

- Oil and grease in the ground water 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 ground water 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 Ground Water, Surface Water, and Leachate).

Factors affecting the design of an ion exchange system include the presence of oil and grease, contaminant concentration, exchange capacity of the resin, suspended solids, metals, oxidant content, inorganic ions in ground water; and pH of the ground water.

TOP

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.

TOP

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.

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Site Information:

- EPA Demo Kerr-McGee Chemical Corp., WI
- Army Demo USACE-WES, MS
- Additional site information on the FRTR web site

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A list of vendors offering Ex Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Technology>> Ground Water, Surface Water, and Leachate >>3.12 Ex Situ Physical/Chemical Treatment (assuming pumping) >>4.49 Precipitation/Coagulation/Flocculation

Introduction>> 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.

Description:

Figure 4-49:
Typical Metals Precipitation Process

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 ground water containing heavy metals, including their radioactive isotopes. In ground water 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.

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. 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. In some cases, process design will allow for the generation of sludges that can be sent to recyclers for metal recovery.

➢ *Coagulants and Flocculation*

In the precipitation process, chemical precipitants, coagulants, and flocculantation are used to increase particle size through aggregation. The precipitation process can generate very fine particles that are held in suspension by electrostatic surface charges. These charges cause clouds of counter-ions to form around the particles, giving rise to repulsive forces that prevent aggregation and reduce the effectiveness of subsequent solid-liquid separation processes. Therefore, chemical coagulants are often added to overcome the repulsive forces of the particles. The three main types of coagulants are inorganic electrolytes (such as alum, lime, ferric chloride, and ferrous sulfate), organic polymers, and synthetic polyelectrolytes with anionic or cationic functional groups. The addition of coagulants is followed by low-sheer mixing in a flocculator to promote contact between the particles, allowing particle growth through the sedimentation phenomenon called flocculant settling.

Flocculant settling refers to a rather dilute suspension of particles that coalesce, or flocculate, during the sedimentation operation. As coalescence or flocculation occurs, the particles increase in mass and settle at a faster rate. The amount of flocculation that occurs depends on the opportunity for contact, which varies with the overflow rate, the depth of the basin, the velocity gradients in the system, the concentration of particles, and the range of particles sizes. The effects of these variables can only be accomplished by sedimentation tests.

TOP

Synonyms:

NA.

TOP

Applicability:

Precipitation is used mainly to convert dissolved ionic species into solid-phase particulates that can be removed from the aqueous phase by coagulation and filtration. Remedial application of this technology usually involve removal of dissolved toxic metals and radionuclides. Depending on the process design, sludges may be amenable to metal recovery.

TOP

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 ground water 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.
- Soluble hexavalent chrome requires extra treatment prior to coagulaation and flocculation.
- 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 need to be added to the water to achieve adequate settling of solids.
- Treated water will often require pH adjustment.
- Metals held in solution by complexing agents (e.g., cyanide or EDTA) are difficult to precipitate.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, 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].

TOP

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 ground water treatment. Precipitation (combined with sedimentation, and/or flocculation and filtration) is becoming the most widely selected means

for heavy metals removal from ground water in pump and treat operations.

TOP

Cost:

This cost estimate is does not include the costs for additional treatment steps which may be necessary when employing precipitation/coagulation/flocculation technology such as the sludge dewatering and disposal. For budgetary purposes, sludge disposal may be estimated to increase operating costs by approximately $0.50 per 1,000 gallons of ground water treated. The key cost driver information and cost analysis was developed using the 2006 version of the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- No sensitivity analysis possible as only variable is influent flow rate.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply precipitation/coagulation/flocculation technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

GW TECHNOLOGY:	Precipitation/Coagulation/Flocculation	
RACER PARAMETERS	Scenario A and B	Scenario C a
	Small Site	**Large Sit**
	No Cost Sensitivity Possible	**No Cost Sensitivity**
THOUSAND GALLONS TREATED PER YEAR	**10,512**	**34,164**
COST PER THOUSAND GALLONS PER YEAR	**$41**	**$17**

Detailed Cost Estimate

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References:

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Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

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Site Information:

- EPA Demo Palangana Uranium Mine Site, TX
- Coakley Landfill New Hampshire
- Stringfellow Acid Pit Site CA
- Winthrop Landfill Winthrop, ME
- EPA Removal Action Crown Plating, MO
- Coastal Systems Station, AOC 1, Panama City, FL
- **Additional site information on the FRTR web site**

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A list of vendors offering En Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Technology>> Ground Water, Surface Water, and Leachate
>>3.12 Ex Situ Physical/Chemical Treatment (assuming pumping)
>>4.50 Separation

Introduction>> Separation techniques concentrate contaminated waste water through physical and chemical means.

Description:

Figure 4-50a Typical Distillation System

Figure 4-50b Typical Filtration System

Figure 4-50c: Typical Freeze Crystallization System

Figure 4-50d Typical Membrane Pervaporation/Reverse Osmosis System

Separation processes seek to detach contaminants from their medium (i.e., ground water and/or binding material that contain them). Ex situ separation of waste stream can be performed by many processes: (1) distillation, (2) filtration/ultrafiltration/microfiltration, (3) freeze crystallization, (4) membrane pervaporation and (5) reverse osmosis.

➢ *Distillation*

Distillation is a chemical separations process involving vaporization and condensation that is used to separate components of varying vapor pressures (volatilities) in a liquid or gas stream. Simple distillation involves a single stage operation in which heat is applied to a liquid mixture in a still, causing a portion of the liquid to vaporize. These vapors are subsequently cooled and condensed producing a liquid product called distillate or overhead product. The distillate is enriched with the higher volatility components. Conversely, the mixture remaining in the still is enriched with the less volatile components. This mixture is called the bottoms product. Multiple staging is utilized in most commercial distillation operations to obtain better separation of organic components than is possible in a single evaporation and condensation stage.

➢ *Filtration/Ultrafiltration/Microfiltration*

Filtration is the physical process of mechanical separation based on particle size whereby particles suspended in a fluid are separated by forcing the fluid through a porous medium. As fluid passes through the medium, the suspended particles are trapped on the surface of the medium and/or within the body of the medium. Ultrafiltration/ microfiltration occurs when particles are separated by forcing fluid through a semipermeable membrane. Only the particles whose size are smaller than the openings of the membrane are allowed to flow through.

➢ *Freeze Crystallization*

Freeze crystallization processes removes purified solvent from solution as frozen crystals. When a solution containing dissolved contaminants is slowly frozen, water ice crystals form on the surface,

and the contaminants are concentrated in the remaining solution (called "mother liquor"). The ice crystals can be separated from the mother liquor, washed and melted to yield a nearly pure water stream. The contaminated waste stream, mother liquor, and any precipitated solids, are generally more amenable to subsequent treatment by conventional destruction and stabilization technologies due to the higher concentrations.

➢ *Membrane Pervaporation*

Membrane pervaporation is a process that uses permeable membranes that preferentially adsorb volatile organic compounds (VOCs) from contaminated water. Contaminated water first passes through a heat exchanger, raising the water temperature. The heated water then enters the pervaporation module, containing membranes composed of a nonporous organophilic polymer, similar to silicone rubber, formed into capillary fibers. VOCs diffuse by vacuum from the membrane-water interface through the membrane wall. Treated water exits the pervaporation module, while the organic vapors travel from the module to a condenser where they return to the liquid phase. The condensed organic materials represent only a fraction of the initial wastewater volume and may be subsequently disposed of at a cost savings.

➢ *Reverse Osmosis*

The membrane pervaporation process can be modified by using reverse osmosis. In reverse osmosis water is forced through the pervaporation module under pressure. The module containing the membrane(s), of which there are many types depending on the application, allows water free of contaminants to pass through. The water containing the contaminants that were not able to pass through the membrane is recirculated back to the pervaporation module for further treatment, where the organic vapors (called permeate) are extracted by vacuum, condensed and vented downstream of the condenser, thus minimizing air releases.

TOP

Synonyms:

NA

TOP

Applicability:

The ex situ separation process is used mainly as a pretreatment or post-treatment process to remove contaminants from waste water. It can be applied to aqueous waste streams such as ground water, lagoons, leachate, and rinse water. Industrial waste streams may also be treated with these processes. The target contaminant groups for ex situ separation processes are VOCs, SVOCs, pesticides, and suspended particles. Solvents may be recovered for reuse.

TOP

Limitations:

Factors that may limit the applicability and effectiveness of these processes include:

- Membrane pervaporation and freeze crystallization are limited to only aqueous waste streams.
- The presence of oil and grease contaminants may interfere with these processes by decreasing flow rate.
- Space must be adequate for distillation and freeze crystallization treatment systems. Distillation units are comparatively tall and can cover large areas.
- Compounds that decompose or polymerize at the operating temperature and are explosive are not desirable in distillation.
- In freeze crystallization, eutectic mixtures form as solutions become more concentrated; feed stream must be dilute enough to accomplish significant volume reduction before a eutectic mixture forms.

Data Needs:

A detailed discussion of data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, Surface Water, and Leachate).

TOP

Performance Data:

Performance data on distillation and freeze crystillation are not available.

A pilot-plant was evaluated using membrane pervaporation at Wastewater Technology Centre (WTC) by ZENON Environmental Inc. and field tested in 1992. The technology had a removal efficiency of 99 percent. A cost comparison performed in 1992 by WTC and ZENON showed that pervaporation can be competitive with air stripping and activated carbon to treat low VOC concentrations.

TOP

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. The cost of freezed crystallization is estimated to be only $0.03 per gallon for a 40 gpm facility.

Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes (HTRW) Historical Cost Analysis System (HCAS) developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group.

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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Canning, P. and Chris L., 1995. "Cross-flow Pervaporation System", Zenon Environmental Inc.

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.

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Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Innovative Groundwater Treatment Technologies*, EPA/542/R-98/015.

- PerVap™ Membrane Separation Groundwater Treatment at DOE's Pinellas Northeast Site, Largo, Florida

Turner, R., 1995. "Update on Zenon Pervaporation", Ground Water Currents, Issue No.13.

TOP

Site Information:

- Wastewater Technology Center
- EPA & DOE Demo Rocky Flats Facility, CO
- EPA Demo American Creosote Works, FL
- DOI Demo Birmingham, AL; Manassas, VA
- DOI Demo Bureau of Mines and USAEC (Cooperative effort) Buffalo, NY
- EPA SITE Demo Selma Pressure Treating Selma, CA
- DOE Integrated Demo,4 DOE sites:
  (1) Hanford
  (2) Fernald, ID
  (3) Oak Ridge
  (4) Savannah River
- DOI, Army, EPA Demo Saginaw Bay Confined Disposal Facility, MI; Toronto, Canada
- EPA Demo Palmerton Zinc Superfund Site, PA
- Naval Air Station North Island, San Diego, CA
- DOE's Pinellas Northeast Site, Largo, FL (PerVap Membrane Separation)
- Additional site information on the FRTR web site

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering Ex Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Hazard Analysis

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Technology>> Ground Water, Surface Water, and Leachate
>>3.12 Ex Situ Physical/Chemical Treatment
>>4.51 Sprinkler Irrigation

Introduction>> The process involves the pressurized distribution of VOC-laden water through a standard sprinkler irrigation system.

Description:

Figure 4-51:
Typical Trickling Filter System Sprinkler irrigation is a relatively simple treatment technology used to volatilize VOCs from contaminated wastewater. The process involves the pressurized distribution of VOC-laden water through a standard sprinkler irrigation system. Sprinkler irrigation transfers VOCs from the dissolved aqueous phase to the vapor phase, whereby the VOCs are released directly to the atmosphere.

TOP

Synonyms:

NA.

TOP

Applicability:

Sprinkler irrigation can be utilized for any contaminant that readily transfers from the dissolved phase to the vapor phase (VOCs). The target contaminant groups for trickling filters are VOCs, SVOCs, fuels, explosives, and pesticides.

TOP

Limitations:

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

- Regulatory approval may be difficult to obtain because of the potential of direct release for contaminants to the atmosphere.
- Ponding of wastewater may result from heavy irrigation.
- Metal contaminated wastewater can't be treated.
- Performance may be effected by temperature.
- As CAA requirements become stricter, this technology may become obsolete.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, Surface Water, and Leachate).

TOP

Performance Data:

Since sprinkler irrigation is a new process, little detailed or meaningful performance information is available.

TOP

Cost:

Not available at this time.

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

Battelle, 1997. "Remediation Technologies for Typical Contaminants and Media Types at Navy Sites," prepared for Naval Facilities Engineering Service Center Technology Application Branch, CA 93043.

TOP

Site Information:

- Harris County

Points of Contact:

TOP

General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

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A list of vendors offering Ex Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

To be added

TOP

Technology>> Ground Water, Surface Water, and Leachate >>3.13 Containment >>4.52 Physical Barriers

Introduction>> 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 ground water flow.

Description:

Figure 4-52:
Typical Keyed-In Slurry Wall (Cross-Section) Physical barriers (or slurry walls) are used to contain contaminated ground water, divert contaminated ground water from the drinking water intake, divert uncontaminated ground water flow, and/or provide a barrier for the ground water treatment system.

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 ground water 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 ground water; however, in contaminated ground water 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. The bentonite slurry is used primarily for wall stabilization during trench excavation. A soil-bentonite backfill material is then placed into the trench (displacing the slurry) to create the cutoff wall. Walls of this composition provide a barrier with low permeability and chemical resistance at low cost. Other wall compositions, such as cement/bentonite, pozzolan/bentonite, attapulgite, organically modified bentonite, or slurry/geomembrane composite, 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 up to 30 meters (100 feet) and are generally 0.6 to 1.2 meters (2 to 4 feet) in thickness. Installation depths over 30 m (100 ft) are implementable using clam shell bucket excavation, but the cost perunit area of wall increases by about a factor of three. 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 ground water 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.

TOP

Synonyms:

Vertical cutoff walls; Hydrodynamic barriers; Slurry Trenches, Slurry Walls.
DSERTS Code: I2 (Slurry Walls/Underground Barriers)

TOP

Applicability:

Slurry walls contain the ground water itself, thus treating no particular target group of contaminants. They are used to contain contaminated ground water, divert contaminated ground water from drinking water intake, divert uncontaminated ground water flow, and/or provide a barrier for the ground water treatment system.

TOP

Limitations:

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

- Most of the approaches involve a large amount of heavy construction.
- 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.
- Use of this technology does not guarantee that further remediation in the future may not be necessary.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.2. (Data Requirements for Ground Water, 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.

TOP

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.

TOP

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).
- Planning, permitting, regulatory interaction, and site restoration.

Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes (HTRW) Historical Cost Analysis System (HCAS) developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group.

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References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

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Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

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EPA, 1997. *Technology Alternatives for the Remediation of Soils Contaminated with As, Cd, Cr, Hg, and Pb,* Engineering Bulletin, EPA540/R-97/008.

EPA, 1998. *Evaluation of Subsurface Engineered Barriers at Waste Sites,* Technology Report, EPA/542/R-98/005.

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: Groundwater Pump and Treat (Nonchlorinated Solvents)*, EPA/542/R-98/014

- Pump and Treat and Containment of Contaminated Groundwater at the Sylvester/Gilson Road Superfund Site, Nashua, New Hampshire

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.

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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.

TOP

Site Information:

- Hazardous Waste Landfill
- Sanitary Landfill
- Coal Tar Disposal Pond
- Sylvester/Gilson Road Superfund Site, Nashua, NH

Points of Contact:

TOP

General FRTR Agency Contacts

Technology Specific Web Site:

Government Web Sites

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Vendor Information:

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A list of vendors offering In Situ Physical/Chemical Water Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Technology>> Ground Water, Surface Water, and Leachate >>3.13 Containment >>4.53 Deep Well Injection

Introduction>> Deep well injection is a liquid waste disposal technology. This alternative uses injection wells to place treated or untreated liquid waste into geologic formations that have no potential to allow migration of contaminants into potential potable water aquifers.

Description:

Figure 4-53:
Typical Deep Well Injection System

A typical injection well consists of concentric pipes, which extend several thousand feet down from the surface level into highly saline, permeable injection zones that are confined vertically by impermeable strata. The outermost pipe or surface casing, extends below the base of any underground sources of drinking water (USDW) and is cemented back to the surface to prevent contamination of the USDW. Directly inside the surface casing is a long string casing that extends to and sometimes into the injection zone. This casing is filled in with cement all the way back to the surface in order to seal off the injected waste from the formations above the injection zone back to the surface. The casing provides a seal between the wastes in the injection zone and the upper formations. The waste is injected through the injection tubing inside the long string casing either through perforations in the long string or in the open hole below the bottom of the long string. The space between the string casing and the injection tube, called the annulus, is filled with an inert, pressurized fluid, and is sealed at the bottom by a removable packer preventing injected wastewater from backing up into the annulus.

TOP

Synonyms:

Subsurface injection, Underground injection, Class I injection wells.

TOP

Applicability:

The target contaminant groups for deep well injection are VOCs, SVOCs, fuels, explosives, and pesticides. However, existing permitted deep well injection facilities are limited to a narrow range of specific wastes. Success at expanding existing permits to manage hazardous wastes seems unlikely.

TOP

Limitations:

Factors that may limit the applicability and effectiveness of these processes include:

- Injection will not be used for hazardous waste disposal in any areas where seismic activity could potentially occur.
- Injected wastes must be compatible with the mechanical components of the injection well system and the natural formation water. The waste generator may be required to perform physical, chemical, biological, or thermal treatment for removal of various contaminants or constituents from the waste to modify the physical and chemical character of the waste to assure compatibility.
- High concentrations of suspended solids (typically >2 ppm) can lead to plugging of the injection interval.
- Corrosive media may react with the injection well components, with injection zone formation, or with confining strata with very undesirable results. Wastes should be neutralized.
- High iron concentrations may result in fouling when conditions alter the valence state and convert soluble to insoluble species.
- Organic carbon may serve as an energy source for indigenous or injected bacteria resulting in rapid population growth and subsequent fouling.
- Waste streams containing organic contaminants above their solubility limits may require pretreatment before injection into a well.
- Site assessment and aquifer characterization are required to determine suitability of site for wastewater injection.
- Extensive assessments must be completed prior to receiving approval from regulatory authority.

TOP

Data Needs:

A detailed discussion of data elements is provided in Subsection 2.2.2 (Data Requirements for Ground Water, Surface Water, and Leachate).

TOP

Performance Data:

Injection wells have been used for the disposal of industrial and hazardous wastes since the 1950s, so the equipment and methodology are readily available and well known; however the use of them today is continuing under very strict regulatory control.

TOP

Cost:

NA

TOP

References:

Innovative Remediation Technologies: Field Scale Demonstration Project in North America, 2nd Edition

Abstracts of Remediation Case Studies, Volume 4, June 2000, EPA 542-R-00-006

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects - Revised Version, October, 1998, EPA 542-B-98-007

EPA, 1985. *Report to Congress on Injection of Hazardous Waste*, EPA, Office of Drinking Water, EPA/9-85-003.

Reeder et al., 1977. *Review and Assessment of Deep Well Injection of Hazardous Waste, Volume I*, EPA/600/2-77/029a.

Warner and J.H.Lehr, 1977. *An Introduction to the Technology of Subsurface Wastewater Injection*,

EPA/600/2-77/240.

TOP

Site Information:

- DOI Demo Bureau of Mines Tuscaloosa Research Center, AL

Points of Contact:

TOP

General FRTR Agency Contacts

Technology Specific Web Sites:

NA

Vendor Information:

TOP

A list of vendors offering Water Containment Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

To be added

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Technology>> Air Emissions/Off-Gas Treatment
>>3.14 Air Emissions/Off-Gas Treatment
>>4.54 Biofiltration

Introduction>> 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.

Description:

Figure 4-54: Typical Methanotrophic Biofilm Reactor Diagram

Biofiltration is a low-cost and highly effective air pollution control (APC) technology in which vapor-phase organic contaminants are passed through a bed of porous media and sorb to the media surface where they are degraded by microorganisms in the media. 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 granulated activated carbon (GAC) technologies.

TOP

Synonyms:

NA

TOP

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.

TOP

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.

- Compounds that are recalcitrant to biodegratation will not be converted to harmless products.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.3. (Data Requirements for Air Emissions/Off-Gases).

TOP

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.

TOP

Cost:

Cost estimates range from $5 to $10 per kilogram of contaminant ($2.27 to $4.54 per pound).

TOP

References:

USAEC, 1997. "Remediation of Air Streams Contaminated with Trichloroethylene Using Biofiltration at Anniston Army Depot" in *Innovative Technology Demonstration, Evaluation and Transfer Activities, FY 96 Annual Report,* Report No. SFIM-AEC-ET-CR-97013, pp. 19-20.

TOP

Site Information:

- SITE Emerging Technology (Membrane Technology and Process, Inc.)
- SITE Emerging Technology (Remediation Technologies, Inc.)

Points of Contact:

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Technology Specific Web Sites:

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Vendor Information:

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A list of vendors offering Air Emission/Off-Gas Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization

Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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Technology>> Air Emissions/Off-Gas Treatment
>>3.14 Air Emissions/Off-Gas Treatment
>>4.55 High Energy Destruction

Introduction>> The high energy destruction process uses high-voltage electricity to destroy VOCs at room temperature.

Description:

Figure 4-55: Typical Low temperature Plasma Reactor The high energy destruction technology is one of many approaches toward decontaminating of air emissions off-gases prior to atmospheric release. The objective of the HEC technology is to provide a standalone, field-portable means of treating off-gases produced during other remedial operations.

➢ *High Energy Corona*

The High Energy Corona (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.

➢ *Tunable Hybrid Plasma Reactor*

Researchers at the Massachusetts Institute of Technology (MIT) are investigating plasma chemical processes relevant to the development of a versatile mobile versatile mobile electron-beam driven plasma reactor for efficient on-site decomposition of carbon tetrachloride (CCl_4) and other VOCs.

The reactor uses a moderate energy electron beam (100-300 keV) that is injected into atmospheric air containing the organic contaminants. The organics are destroyed or oxidized to non-toxic chemicals through their interaction with the electrons and plasma generated from the electron beam. Since a plasma is generated, use of either alternating current (AC) or direct current (DC)

electric fields allows a further increase in the electron and gas temperatures to optimize the treatment process. The high degree of tunability of the reactor gave rise to the name tunable hybrid plasma (THP) reactor.

TOP

Synonyms:

NA

TOP

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.

The THP technology is best suited for treatment of gaseous streams with small concentrations of VOCs especially chlorinated compounds.

TOP

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.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.3. (Data Requirements for Air Emissions/Off-Gases).

TOP

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 ppm 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.

TOP

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.

TOP

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.

DOE, 1994. *Technology Catalogue*, First Edition. February.

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.

TOP

Site Information:

- DOE Savannah River

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Non Government Web Sites

Vendor Information:

TOP

A list of vendors offering Air Emission/Off-Gas Treatment is available from EPA REACH IT which

combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

TOP

Hazard Analysis

TOP

Technology>> Air Emissions/Off-Gas Treatment
>>3.14 Air Emissions/Off-Gas Treatment
>>4.56 Membrane Separation

Introduction>> 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)..

Description:

Figure 4-56:
Typical Membrane Separation Diagram

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.

TOP

Synonyms:

NA

TOP

Applicability:

The targeted contaminants are VOCs, carbon tetrachloride, and chloroform in gas streams.

TOP

Limitations:

Limitations of this technology are:

- Inability to handle fouling constituents in soil.
- Inability to handle fluctuations in VOC concentrations.
- Membranes are sensitive to moisture.

TOP

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.3. (Data Requirements for Air Emissions/Off-Gases).

TOP

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.

TOP

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.

TOP

References:

DOE, 1994. *Technology Catalogue*, First Edition. February.

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.

TOP

Site Information:

- DOE Hanford
- NEL Demo: NAS North Island Installation Restoration (IR) Site 9

Points of Contact:

TOP

General FRTR Agency Contacts

Technology Specific Web Sites:

Non Government Web Sites

Vendor Information:

TOP

A list of vendors offering Air Emission/Off-Gas Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

TOP

To be added

TOP

Technology>> Air Emissions/Off-Gas Treatment >>3.14 Air Emissions/Off-Gas Treatment >>4.57 Oxidation

Introduction>> 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.

Description:

Figure 4-57:
Typical Oxidation Diagram

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 °C to 1,600 °F), and gas residence times are typically 1 second or less.

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 °C to 370 °C (600 °C 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.

➢ *Catalytic Oxidation*

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.

➢ *Internal Combustion Engine Oxidation*

Organic contaminants in air can be used as fuel and burned in an internal combustion engine. When the concentration of organics is too low, auxiliary fuel is added to enhance the oxidation.

➢ *Thermal Oxidation*

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.

➢ *UV Oxidation*

Oxidation of organic contaminants in air can also be achieved by UV oxidation. As described in UV Oxidation of Wastewater (Technology Profile Section 4.44), UV oxidation is the process by which chemical bonds of the contaminants are broken under the influence of UV light. Products of photo-degradation vary according to the matrix in which the process occurs, but the complete conversion of an organic contaminant to CO_2, H_2O, etc. is not probable.

TOP

Synonyms:

DSERTS Code: F21 (UV Oxidation)

TOP

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.

TOP

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 for catalytic and thermal oxidation.
- The presence of chlorinated hydrocarbons (see comment above) and some heavy metals (e.g., lead) may poison a particular catalyst.

TOP

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.

TOP

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 ground water.

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.

TOP

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. The key cost driver information and cost analysis was developed using the 2006 version of the Remedial Action Cost Engineering and Requirements (RACER) software.

Key Cost Drivers

- Approach
    - Catalytic oxidation is more expensive than thermal oxidation at low flow rates, vice versa for high flow rates. Additionally, thermal oxidation is more economical at very high VOC concentrations and catalytic oxidation is more economical at moderate VOC concentrations. Commonly at the start of a project VOC concentrations are high for a limited time and the leasing option for a thermal unit should be evaluated for this limited duration. No other sensitivity analysis is feasible.

Cost Analysis

The following table represents estimated costs (by common unit of measure) to apply oxidation technology at sites of varying size and complexity. A more detailed cost estimate table which includes specific site characteristics and significant cost elements that contributed to the final costs can be viewed by clicking on the link below.

EMISSION TECHNOLOGY:	Oxidation			
RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small Site		Large Site	
	Easy	Difficult	Easy	Difficult
THOUSAND SCFM TREATED PER YEAR	105,120	105,120	1,051,200	1,051,200
COST PER THOUSAND SCFM	$0.72	$0.83	$0.17	$0.24

SCFM = Standard Cubic Feet per Minute

Detailed Cost Estimate

TOP

References:

California Base Closure Environmental Committee (CBCEC), 1994. *Treatment Technologies Applications Matrix for Base Closure Activities, Revision 1*, Technology Matching Process Action Team, November, 1994.

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.

EPA, 1997. *On-Site Incineration: Overview of Superfund Operating Experience.*

Federal Remediation Technologies Roundtable, 1995. *Remediation Case Studies: Soil Vapor Extraction*, EPA/542/R-95/004.

- Soil Vapor Extraction at the North Fire Training Area (NFTA), Luke AFB, Arizona
- In Situ Soil Vapor Extraction at McClellan Air Force Base, California
- Soil Vapor Extraction at the SMS Instruments Superfund Site, Deer Park, New York

Federal Remediation Technologies Roundtable, 1997. *Remediation Case Studies: Soil Vapor Extraction and Other In Situ Technologies*, EPA/542/R-97/009.

- Flameless Thermal Oxidation at the U.S. Department of Energy's Savannah River Site, M Area, Aiken, South Carolina (In Cooperation With the U.S. Department of Energy, Oak Ridge Operations)

Federal Remediation Technologies Roundtable, 1998. *Remediation Case Studies: In Situ Soil Treatment Technologies (Soil Vapor Extraction, Thermal Processes)*, EPA/542/R-98/012

- Soil Vapor Extraction at Site ST-35, Davis-Monthan AFB, Arizona
- Photolytic Destruction Technology Demonstration at NAS North Island, Site 9, San Diego, California

TOP

Site Information:

- Dover AFB
- Wurtsmith AFB
- Former gasoline service station, Santa Monica, CA
- NEL Demo: NAS North Island Installation Restoration (IR) Site 11
- Site ST-35, Davis-Monthan AFB, AZ
- North Fire Training Area (NFTA), Luke AFB, AZ
- McClellan AFB, Operable Unit D, Site S, CA
- NAS North Island, Site 9, San Diego, CA
- SMS Instruments Superfund Site, Deer Park, NY
- U.S. Department of Energy (DOE), Savannah River Site, M Area Process Sewer/Integrated Demonstration Site, Aiken, SC

Points of Contact:

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Vendor Information:

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Government Disclaimer

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Health and Safety:

Hazard Analysis

TOP

Technology>> Air Emissions/Off-Gas Treatment
>>3.14 Air Emissions/Off-Gas Treatment
>>4.58 Scrubbers

Introduction>> Scrubber is an air washer with refinement device which is used for cleaning gases from soluble or particulates. It even treats fumes on line.

Description:

Figure 4-58:
Typical Scrubber Diagram

Generally, there are two broad classifications of air pollution controls referred to as scrubbers:

➢*Wet Scrubbers*

Wet scrubbers remove air pollutants by inertial of diffusional impaction, reaction with a sorbent or reagent slurry, or absorbtion into a liquid
solvent. These types of scrubbers can be used to control particulate matter (PM), including particulate matter less than or equal to 10 micrometers (μm) in aerodynamic diameter (PM10), particulate matter less than or equal to 2.5 μm in aerodynamic diameter (PM2.5), and hazardous air pollutants (HAP) in particulate form (PMHAP); and inorganic fumes, vapors, and gases (e.g., chromic acid, hydrogen sulfide, ammonia, chlorides, fluorides, and SO_2). These types of scrubbers may also occasionally be used to control volatile organic compounds (VOC). Hydrophilic VOC may be controlled with an aqueous fluid, and hydrophobic VOC may be controlled with an amphiphilic block copolymer in the water. However, very little data exist for this application. When using absorption as the primary control technique, the spent solvent must be easily regenerated or disposed of in an environmentally acceptable manner (EPA, 1991).

Configurations of Wet Scrubbers

Orifice scrubbers form a category of gas-atomized spray scrubbers in which a tube or a duct of some other shape forms the gas-liquid contacting zone. The particle-laden gas stream is forced to pass over the surface of a pool of scrubbing liquid at high velocity, entraining it as droplets as it enters an orifice. The gas stream flowing through the orifice atomizes the entrained liquid droplets in essentially the same manner as a venturi scrubber. As the gas velocity and turbulence increases with the passing of the gas through the narrow orifice, the interaction between the PM and atomized liquid droplets also increases. Particulate matter and droplets are then removed from the gas stream by impingement on a series of baffles that the gas stream encounters after exiting the orifice. The collected liquid and PM drain from the baffles back into the liquid pool below the orifice (Perry, 1984; EPA, 1998). The scrubbing liquid is fed into the pool at the bottom of the scrubber and later recirculated from the entrainment separator baffles by gravity instead of being circulated by a pump as in venturi scrubbers. Many devices using contactor ducts of various shapes are offered commercially. The principal advantage of this scrubber is the elimination of a pump for recirculation of the scrubbing liquid (Perry, 1984; EPA, 1998).

A *venturi scrubber* accelerates the waste gas stream to atomize the scrubbing liquid and to improve gas-liquid contact. In a venturi scrubber, a "throat" section is built into the duct that forces the gas

stream to accelerate as the duct narrows and then expands. As the gas enters the venturi throat, both gas velocity and turbulence increase. Depending upon the scrubber design, the scrubbing liquid is sprayed into the gas stream before the gas encounters the venturi throat, or in the throat, or upwards against the gas flow in the throat. The scrubbing liquid is then atomized into small droplets by the turbulence in the throat and droplet-particle interaction is increased. Some designs use supplemental hydraulically or pneumatically atomized sprays to augment droplet creation. The disadvantage of these designs is that clean liquid feed is required to avoid clogging (EPA, 1998; AWMA, 1992; Corbitt, 1990). After the throat section, the mixture decelerates, and further impacts occur causing the droplets to agglomerate. Once the particles have been captured by the liquid, the wetted PM and excess liquid droplets are separated from the gas stream by an entrainment section which usually consists of a cyclonic separator and/or a mist eliminator (EPA, 1998; Corbitt, 1990). Current designs for venturi scrubbers generally use the vertical downflow of gas through the venturi throat and incorporate three features: (1) a "wet-approach" or "flooded-wall" entry section to avoid a dust buildup at a wet-dry junction; (2) an adjustable throat for the venturi throat to provide for adjustment of the gas velocity and the pressure drop; and (3) a "flooded" elbow located below the venturi and ahead of the entrainment separator, to reduce wear by abrasive particles. The venturi throat is sometimes fitted with a refractory lining to resist abrasion by dust particles (Perry, 1984).

In *fiber-bed scrubbers*, moisture-laden waste gas passes through beds or mats of packing fibers, such as spun glass, fiberglass, or steel. If only mists are to be collected, small fibers may be used, but if solid particles are present, the use of fiber-bed scrubbers is limited by the tendency of the beds to plug. For PM collection, the fiber mats must be composed of coarse fibers and have a high void fraction, to minimize the tendency to plug. The fiber mats are often sprayed with the scrubbing liquid so particles can be collected by deposition on droplets and fibers. For PM removal, the scrubber design may include several fiber mats and an impingement device. The final fiber mat is typically dry for the removal of any droplets which are still entrained in the gas stream (EPA, 1998; Perry, 1984).

Mechanical scrubbers comprise those devices in which a power-driven rotor produces the fine spray and the contacting of gas and liquid. As in other types of scrubbers, it is the droplets that are the principal collecting bodies for the dust particles. The rotor acts as a turbulence producer. An entrainment separator must be used to prevent carry-over of spray. The simplest commercial devices of this type are essentially fans upon which water is sprayed (Perry, 1984). Mechanically-aided scrubbers are usually preceded by a cyclone or other precleaner for removal of coarse dust and larger debris (Avallone, 1996; AAF, 1999). This type of scrubber relies almost exclusively on inertial interception for PM collection, and is capable of high collection efficiencies, but only with commensurate high energy consumption (EPA, 1998; Josephs, 1999).

An *impingement-plate scrubber* is a vertical chamber with plates mounted horizontally inside a hollow shell. Impingement-plate scrubbers operate as countercurrent PM collection devices. The scrubbing liquid flows down the tower while the gas stream flows upward. Contact between the liquid and the particle-laden gas occurs on the plates. The plates are equipped with openings that allow the gas to pass through. Some plates are perforated or slotted, while more complex plates have valve-like openings (EPA, 1998). The simplest impingement-plate scrubber is the sieve plate, which has round perforations. In this type of scrubber, the scrubbing liquid flows over the plates and the gas flows up through the holes. The gas velocity prevents the liquid from flowing down through the perforations. Gas-liquid- particle contact is achieved within the froth generated by the gas passing through the liquid layer. Complex plates, such as bubble cap or baffle plates, introduce an additional means of collecting PM. The bubble caps and baffles placed above the plate perforations force the gas to turn before escaping the layer of liquid. While the gas turns to avoid the obstacles, most PM cannot and is collected by impaction on the caps or baffles. Bubble caps and the like also prevent liquid from flowing down the perforations if the gas flow is reduced (EPA, 1998). In all types of impingement-plate scrubbers, the scrubbing liquid flows across each plate and down the inside of the tower onto the plate below. After the bottom plate, the liquid and collected PM flow out of the bottom of the tower. Impingement-plate scrubbers are usually designed to provide operator access to each tray, making them relatively easy to clean and maintain. Consequently, impingement-plate scrubbers are more suitable for PM collection than packed-bed scrubbers. Particles greater than 1 μm in aerodynamic diameter can be collected effectively by impingement-plate scrubbers, but many particles <1 μm in aerodynamic diameter will penetrate these devices (EPA, 1998).

Spray scrubbers consist of empty cylindrical or rectangular chambers in which the gas stream is contacted with liquid droplets generated by spray nozzles. A common form is a spray tower, in which the gas flows upward through a bank or successive banks of spray nozzles. Similar arrangements are sometimes used in spray chambers with horizontal gas flow. Such devices have very low gas pressure drops, and all but a small part of the contacting power is derived from the

liquid stream. The required contacting power is obtained from an appropriate combination of liquid pressure and flow rate (Perry, 1984). Physical absorption depends on properties of the gas stream and liquid solvent, such as density and viscosity, as well as specific characteristics of the pollutant (s) in the gas and the liquid stream (e.g., diffusivity, equilibrium solubility). These properties are temperature dependent, and lower temperatures generally favor absorption of gases by the solvent. Absorption is also enhanced by greater contacting surface, higher liquid-gas ratios, and higher concentrations in the gas stream (EPA, 1991). Chemical absorption may be limited by the rate of reaction, although the rate-limiting step is typically the physical absorption rate, not the chemical reaction rate (EPA, 1996).

Condensation scrubbing is a relatively recent development in wet scrubber technology. Most conventional scrubbers rely on the mechanisms of impaction and diffusion to achieve contact between the PM and liquid droplets. In a condensation scrubber, the PM act as condensation nuclei for the formation of droplets. Generally, condensation scrubbing depends on first establishing saturation conditions in the gas stream. Once saturation is achieved, steam is injected into the gas stream. The steam creates a condition of supersaturation and leads to condensation of water on the fine PM in the gas stream. The large condensed droplets are then removed by one of several conventional devices, such as a high efficiency mist eliminator (EPA, 1998).

➢ *Dry Scrubbers*

Spray dry scrubbers are a widely used flue-gas desulfurization (FGD) technology. This technology is limited to a flue gas volume of about 200 MWe plants on average, therefore this technology is used in small to medium sized coal fired plants. A removal efficiency of over 90% SO_2 has been achieved using these scrubbers. Some advantages of using this technology are low waste disposal costs, low water consumption and a low pressure drop. Some typical contaminants treated include PAHs, HF, HCl, heavy metals and the previously mentioned SO_2.

Synonyms:

Caustic Scrubbers, Water Scrubbers

TOP

Applicability:

The target contaminant groups for scrubbers are HCL, H_2SO_4, Chlorine, SO_2, acidic vapors and alkaline vapors. Most scrubbers for incinerators handling vapors or liquid wastes are of packed bed design. Acid gases are usually the target of scrubber operations.

TOP

Limitations:

The following factors may limit applicability and effectiveness:

- Definite solubility limits of composition and temperature dependent exist for all minerals in water. Deposition can be avoided by increasing liquid blowdown rate, using only caustic for neutralization or replacing hard scrubber makeup water with deionized water will keep a low level of dissolved salts in the scrubber liquid.
- Operating with excessive dissolved solids. Sodium hypochlorite (NaOCl) is a product of neutralizing Cl_2 with NaOH.. if the scrubber blowdown liquid is acidified (as in a waste water treatment plant) the NaOCl breaks down, releasing Cl_2 gas.
- Improper waste water treatment. Most incinerator flue gas scrubbers are constructed of the least expensive acid proof materials such as polypropylene or similar, and are sensitive to high temperatures. Prior to scrubbing, the hot flue gas must be cooled.
- Waste combustion forms small particles for which additional equipment must be specified. Most flue gas scrubbers recirculate to reduce the rate of blowdown to water treatment. Circulating pump cavitation can sharply reduce the rate of scrubbing liquid available and damage the pump.
- Incorrect pump specification, faulty pump suction piping design, poor scrubber sump design or foreign matter clogging the pump suction.

Data Needs:

A detailed discussion of these data elements is provided in Subsection 2.2.3. (Data Requirements for Air Emissions/Off-Gases).

TOP

Performance Data:

Scrubbers can effectively reduce concentrations of certain water soluble acid, base and organic contaminants. They are used primarily for environmental protection, environmental health, and increasing government regulation. Since the scrubber is so effective at capturing particulates, a filter is necessary to remove them from the system. The filter may be a cleanable or disposable type.

TOP

Cost:

The annualized cost estimates ranges from $3000-$172,000 per m^3 /sec.

TOP

References:

EPA, *Air and Pollution Technology Fact Sheet: Condensation Scrubber.* Provides information about condensation scrubbers. http://www.epa.gov/ttn/catc/dir1/fcondnse.pdf

EPA, *Air and Pollution Technology Fact Sheet: Mechanically aided scrubbers.* Provides information about mechanically aided scrubbers. http://www.epa.gov/ttn/catc/dir1/fmechcal.pdf

EPA, *Air and Pollution Technology Fact Sheet: Fiber- Bed scrubbers.* Provides information about Fiber-Bed scrubbers. http://www.epa.gov/ttn/catc/dir1/fiberbed.pdf

EPA, *Air and Pollution Technology Fact Sheet: Orifice scrubbers.* Provides information about orifice scrubbers.
http://www.epa.gov/ttn/catc/dir1/forifice.pdf

EPA, *Air and Pollution Technology Fact Sheet: Venturi scrubbers.* Provides information about venturi scrubbers.
http://www.epa.gov/ttn/catc/dir1/fventuri.pdfrs.

EPA, *Air and Pollution Technology Fact Sheet: Impingement-Plate/Tray-Tower Scrubber.* Provides information about Impingement-Plate/Tray-Tower Scrubber.
http://www.epa.gov/ttn/catc/dir1/fimpinge.pdf

EPA, *Air and Pollution Technology Fact Sheet: Packed-Bed/Packed-Tower Wet Scrubber.* Provides information about Packed-Bed/Packed-Tower Wet Scrubber.
http://www.epa.gov/ttn/catc/dir1/fpack.pdf

EPA, *Air and Pollution Technology Fact Sheet: Spray-Chamber/Spray-Tower Wet Scrubber.* Provides information about Spray-Chamber/Spray-Tower Wet Scrubber
http://www.epa.gov/ttn/catc/dir1/fsprytwr.pdf

Site Information:

Site Information is not currently available.

TOP

Points of Contact:

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Vendor Information:

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A list of vendors offering Air Emission/Off-Gas Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

Government Disclaimer

Health and Safety:

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>>3.14 Air Emissions/Off-Gas Treatment
>>4.59 Vapor Phase Carbon Adsorption

Introduction>> 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.

Description:

Figure 4-59
Typical Vapor-Phase Carbon Adsorption System 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.

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).

➢ *VOC Recovery and Recycle*

Another more recent technology related to vapor phase carbon absorption is the Brayton-cycle heat pump (BCHP). This technology created by Idaho National Engineering Laboratory offers a method for VOC recovery and recycling. A Brayton-cycle heat pump can condense volatile organic compounds (VOCs) from an air stream, which offers the potential for both recovery and either on-site or off-site recycle of a wide range of VOCs. The VOC-laden air stream can come from either vapor vacuum extraction of soil or air stripping of contaminated ground water.

The technology consists of activated carbon adsorbers located at each extraction well, plus a truck-mounted BCHP to regenerate the adsorbers on a periodic basis. The VOC-laden air from the well is passed through the carbon bed, adsorbing the VOCs. When the bed becomes saturated, hot nitrogen from the regenerator is used to desorb the VOCs from the bed. The nitrogen passes through a chiller, is compressed, and is then cooled in a recuperator, where 50% to 80% of the organics are recovered. The partially depleted nitrogen stream is then expanded through a turbine, lowering the temperature to as low as -150°F and condensing the remaining organics. The now-clean nitrogen passes through the recuperator to cool the VOC-laden nitrogen before returning to the carbon bed. The only outputs will be the clean off-gas from the well and a small amount of recovered organics.

Synonyms:

DSERTS Code: F20 (Carbon Absorption)

TOP

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.

TOP

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.

TOP

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, 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. 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.

TOP

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, 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 effect of 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.

TOP

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TOP

Site Information:

- Commencement Bay, South Tacoma Channel (Well 12), Phase 2, Tacoma, WA

Points of Contact:

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General FRTR Agency Contacts

Technology Specific Web Sites:

Government Web Sites

Vendor Information:

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A list of vendors offering Air Emission/Off-Gas Treatment is available from EPA REACH IT which combines information from three established EPA databases, the Vendor Information System for Innovative Treatment Technologies (VISITT), the Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), and the Innovative Treatment Technologies (ITT), to give users access to comprehensive information about treatment and characterization technologies and their applications.

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Section 5: References

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This reference section has been divided into three subsections:

- 5.1 Document Sources
- 5.2 Reference Document Listing by Author
- 5.3 Reference Web Site Listing

Subsection 5.1 contains points of contact and agencies for obtaining the documents presented in this section. Subsection 5.2 presents a complete listing of all published references excerpted from each source document to this guide or referenced for the 3rd Edition of the Remediation Technologies Screening Matrix and Reference Guide. This subsection has been sorted by author and date of publication. Subsection 5.3 presents a listing of federal agencies, universities, and comapanies with related technical information available on their Web sites. These Web addresses are sorted by host name and by topic.

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Section 5.1: Document Sources

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Documents and reports listed in the following reference listing may be obtained from the following sources:

EPA Documents:

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 Orders: (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 Interior729 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

Notice

Documents available for viewing or downloading from the World Wide Web are linked directly to their corresponding web sites.

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5.2 LISTING BY AUTHOR (A-D)

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The following is a complete listing of all references used this document plus all those presented in the source documents (see Appendix E). Click on the following letter for easy access to alphabetical author list:

A | B | C | D | E | F | G | H | I | J | K | L | M

N | O | P | Q | R | S | T | U | V | W | X | Y | Z

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TOP

FRTR
Remediation Technologies Screening Matrix and Reference Guide, Version 4.0

5.3 Reference Web Site List

Home
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The following is a listing of all web sites referenced in this document. The first column is the name of a federal agency, research institute, or remediation company. The second column indicates the name of remediation technology used by the preceding institute. The last column lists the technology specific Web site. You can click on the Technology name to view its profile, or you can click on the Web Address to see an application of the corresponding technology.

Name	Technology	Web Address
Accutech Remedial Systems	Fracturing	http://www.nttc.edu/env/site95/demo/complete/accutech.html
Advanced Applied Technology Demonstration Facility (AATDF)	Phytoremediation	http://www.ruf.rice.edu/~aatdf/pages/phyto.htm
Advanced Applied Technology Demonstration Facility (AATDF)	Thermal Treatment	http://www.ruf.rice.edu/~aatdf/pages/inducedf.htm
Advanced Applied Technology Demonstration Facility (AATDF)	Phytoremediation	http://www.ruf.rice.edu/~aatdf/pages/phyto.htm
Advanced Applied Technology Demonstration Facility (AATDF)	Thermal Treatment	http://www.ruf.rice.edu/~aatdf/pages/inducedf.htm
Advanced Applied Technology Demonstration Facility (AATDF)	Hydrofracturing	http://www.ruf.rice.edu/~aatdf/pages/inducedf.htm
Advanced Applied Technology Demonstration Facility	Passive/Reactive Treatment Walls	http://www.ruf.rice.edu/~aatdf/pages/passive.htm

(AATDF)		
Advanced Applied Technology Demonstration Facility (AATDF)	Ground Water Pumping	http://www.ruf.rice.edu/~aatdf/pages/spme.htm
AEA Technology, Nat'l Envir. Tech Ctr.	Soil Washing	http://www.nttc.edu/env/site95/emrg/complete/aea.html
AEC	Separation	http://bigisland.ttclients.com/frtr/00000178.html
AEC	Chemical Extraction	http://bigisland.ttclients.com/frtr/00000178.html
AFCEE	Bioventing	http://www.brooks.af.mil/HSC/AL/EQ/prod04.html
AFCEE	Bioventing	http://bigisland.ttclients.com/frtr/00000221.html
AFCEE	Landfarming	http://www.afcee.brooks.af.mil/pro_act/cross/ed27.htm
AFCEE	Land Treatment	http://www.afcee.brooks.af.mil/pro_act/cross/ed27.htm
AFCEE	Excavation, Retrieval, and Off-Site Disposal	http://www.afcee.brooks.af.mil/pro_act/main/fact/fact/dcdd/0495fact.htm
AFCEE	Constructed Wetlands	http://www.wes.army.mil/el/wetlands/wetlands.html
AFCEE	Separation (Water)	http://www.afcee.brooks.af.mil/pro_act/fact/aug99a.htm
American Petroleum Institute	Directional Wells	http://www.api.org/ehs/fpr/4682rh.htm
USACE	Incineration	http://bigisland.ttclients.com/frtr/00000156.html
ARCADIS Geraghty & Miller, Inc.	Enhanced Bioremediation	http://bigisland.ttclients.com/frtr/00000145.html
Atomic Energy of Canada, Limited	Separation (Water)	http://www.nttc.edu/env/site95/emrg/complete/atomic.html
Battelle	Enhanced Bioremediation	http://bigisland.ttclients.com/frtr/00000157.html
Beak Environmental	Enhanced Biodegradation	http://www.beak.com/Services/BioRemediation/BioContribut.htm
Better World	Enhanced Biodegradation	http://www.betterworld.com/BWZ/9608/cover.htm#Bioremediation
Better World	Solar Detoxification	http://www.betterworld.com/BWZ/9608/cover.htm#Solar
Better World	Phytoremediation	http://www.betterworld.com/BWZ/9608/cover.htm#Phytoremediation
BioGenesis Enterprises, Inc.	Soil Washing	http://www.nttc.edu/env/site95/demo/complete/biogene.html
BioTrol, Inc.	Soil Washing	http://www.nttc.edu/env/site95/demo/complete/biotrols.html

BioTrol, Inc.	Bioreactors	http://www.nttc.edu/env/site95/emrg/complete/biotrol.html
Brice Environmental Services Corp.	Soil Washing	http://www.nttc.edu/env/site95/demo/complete/bricenvi.html
Calgon Carbon Corporation	GAC /Liquid Phase Carbon Adsorption	http://www.calgoncarbon.com/
Center for Public Environmental Oversight (CPEO)	Bioventing	http://www.cpeo.org/techtree/ttdescript/bioven.htm
Center for Public Environmental Oversight (CPEO)	Enhanced Biodegradation (In situ)	http://www.cpeo.org/techtree/ttdescript/ensolmx.htm
Center for Public Environmental Oversight (CPEO)	Phytoremediation	http://www.cpeo.org/techtree/ttdescript/phytrem.htm
Center for Public Environmental Oversight (CPEO)	Electrokinetic Separation	http://www.cpeo.org/techtree/ttdescript/elctro.htm
Center for Public Environmental Oversight (CPEO)	Fracturing	http://www.cpeo.org/techtree/ttdescript/fractu.htm
Center for Public Environmental Oversight (CPEO)	Soil Flushing	http://www.cpeo.org/techtree/ttdescript/soilflus.htm
Center for Public Environmental Oversight (CPEO)	Soil Vapor Extraction (In situ)	http://www.cpeo.org/techtree/ttdescript/soilve.htm
Center for Public Environmental Oversight (CPEO)	Solidification/ Stabilization (In situ)	http://www.cpeo.org/techtree/ttdescript/solidsta.htm
Center for Public Environmental Oversight (CPEO)	Thermal Treatment	http://www.cpeo.org/techtree/ttdescript/thevapor.htm
Center for Public Environmental Oversight (CPEO)	Biopiles	http://www.cpeo.org/techtree/ttdescript/biopil.htm
Center for Public Environmental Oversight (CPEO)	Composting	http://www.cpeo.org/techtree/ttdescript/compost.htm
Center for Public Environmental Oversight (CPEO)	Landfarming	http://www.cpeo.org/techtree/ttdescript/lanfarm.htm
Center for Public Environmental Oversight (CPEO)	Slurry Phase Biotreatment	http://www.cpeo.org/techtree/ttdescript/bislurr.htm

Center for Public Environmental Oversight (CPEO)	Chemical Extraction	http://www.cpeo.org/techtree/ttdescript/chemex.htm
Center for Public Environmental Oversight (CPEO)	Chemical Reduction/Oxidation	http://www.cpeo.org/techtree/ttdescript/redoxid.htm
Center for Public Environmental Oversight (CPEO)	Dehalogenation	http://www.cpeo.org/techtree/ttdescript/dehalo.htm
Center for Public Environmental Oversight (CPEO)	Separation	http://www.cpeo.org/techtree/ttdescript/separatn.htm
Center for Public Environmental Oversight (CPEO)	Soil Washing	http://www.cpeo.org/techtree/ttdescript/soilwash.htm
Center for Public Environmental Oversight (CPEO)	Solar Detoxification	http://www.cpeo.org/techtree/ttdescript/soladet.htm
Center for Public Environmental Oversight (CPEO)	Solidification/ Stabilization (Ex situ)	http://www.cpeo.org/techtree/ttdescript/solidsta.htm
Center for Public Environmental Oversight (CPEO)	Hot Gas Decontamination	http://www.cpeo.org/techtree/ttdescript/hotgas.htm
Center for Public Environmental Oversight (CPEO)	Incineration	http://www.cpeo.org/techtree/ttdescript/incinr.htm
Center for Public Environmental Oversight (CPEO)	Open Burning/ Open Detonation	http://www.cpeo.org/techtree/ttdescript/detburn.htm
Center for Public Environmental Oversight (CPEO)	Pyrolysis	http://www.cpeo.org/techtree/ttdescript/pyrols.htm
Center for Public Environmental Oversight (CPEO)	Thermal Desorption	http://www.cpeo.org/techtree/ttdescript/thedesop.htm
Center for Public Environmental Oversight (CPEO)	Landfill Cap	http://www.cpeo.org/techtree/ttdescript/lancap.htm
Center for Public Environmental Oversight (CPEO)	Excavation, Retrieval, and Off-Site Disposal	http://www.cpeo.org/techtree/ttdescript/excdis.htm
Center for Public Environmental Oversight (CPEO)	Co-metabolic Treatment	http://www.cpeo.org/techtree/ttdescript/comevoc.htm
Center for Public Environmental	Enhanced Bioremediation	http://www.cpeo.org/techtree/ttdescript/ensolmx.htm

Oversight (CPEO)	(Water)	
Center for Public Environmental Oversight (CPEO)	Natural Attenuation (Water)	http://www.cpeo.org/techtree/ttdescript/natatt.htm
Center for Public Environmental Oversight (CPEO)	Phytoremediation of Organics	http://www.cpeo.org/techtree/ttdescript/phytrem.htm
Center for Public Environmental Oversight (CPEO)	Air Sparging	http://www.cpeo.org/techtree/ttdescript/airspa.htm
Center for Public Environmental Oversight (CPEO)	Bioslurping	http://www.cpeo.org/techtree/ttdescript/bislurp.htm
Center for Public Environmental Oversight (CPEO)	Directional Wells	http://www.cpeo.org/techtree/ttdescript/horzwel.htm
Center for Public Environmental Oversight (CPEO)	Dual Phase Extraction	http://www.cpeo.org/techtree/ttdescript/dualphex.htm
Center for Public Environmental Oversight (CPEO)	Thermal Treatment	http://www.cpeo.org/techtree/ttdescript/hotwat.htm
Center for Public Environmental Oversight (CPEO)	Hydrofracturing	http://www.cpeo.org/techtree/ttdescript/fractu.htm
Center for Public Environmental Oversight (CPEO)	In-Well Air Stripping	http://www.cpeo.org/techtree/ttdescript/inwellstp.htm
Center for Public Environmental Oversight (CPEO)	Passive/Reactive Treatment Walls	http://www.cpeo.org/techtree/ttdescript/permbarr.htm
Center for Public Environmental Oversight (CPEO)	Bioreactors	http://www.cpeo.org/techtree/ttdescript/biorec.htm
Center for Public Environmental Oversight (CPEO)	Constructed Wetlands	http://www.cpeo.org/techtree/ttdescript/conwet.htm
Center for Public Environmental Oversight (CPEO)	Adsorption/ Absorption	http://www.cpeo.org/techtree/ttdescript/sorpt.htm
Center for Public Environmental Oversight (CPEO)	Air Stripping	http://www.cpeo.org/techtree/ttdescript/airstr.htm
Center for Public Environmental Oversight (CPEO)	GAC /Liquid Phase Carbon Adsorption	http://www.cpeo.org/techtree/ttdescript/liqphs.htm

Center for Public Environmental Oversight (CPEO)	Ion Exchange	http://www.cpeo.org/techtree/ttdescript/ioexch.htm
Center for Public Environmental Oversight (CPEO)	Precipitation/ Coagulation/ Flocculation	http://www.cpeo.org/techtree/ttdescript/precip.htm
Center for Public Environmental Oversight (CPEO)	Separation (Water)	http://www.cpeo.org/techtree/ttdescript/separatn.htm
Center for Public Environmental Oversight (CPEO)	Sprinkler Irrigation	http://www.cpeo.org/techtree/ttdescript/sprirr.htm
Center for Public Environmental Oversight (CPEO)	Advanced Oxidation Processes	http://www.cpeo.org/techtree/ttdescript/uvtreat.htm
Center for Public Environmental Oversight (CPEO)	Ground Water Pumping	http://www.cpeo.org/techtree/ttdescript/pumtre.htm
Center for Public Environmental Oversight (CPEO)	Physical/Biological Barriers	http://www.cpeo.org/techtree/ttdescript/slurwal.htm
Center for Public Environmental Oversight (CPEO)	Biofiltration	http://www.cpeo.org/techtree/ttdescript/biofil.htm
Center for Public Environmental Oversight (CPEO)	High Energy Destruction	http://www.cpeo.org/techtree/ttdescript/hienerg.htm
Center for Public Environmental Oversight (CPEO)	Membrane Separation	http://www.cpeo.org/techtree/ttdescript/memsepa.htm
Center for Public Environmental Oversight (CPEO)	Oxidation	http://www.cpeo.org/techtree/ttdescript/oxidate.htm
Center for Public Environmental Oversight (CPEO)	Vapor Phase Carbon Adsorption	http://www.cpeo.org/techtree/ttdescript/vapphas.htm
Chemfix Technologies, Inc.	Solidification/ Stabilization (Ex situ)	http://www.nttc.edu/env/site95/demo/complete/chemfix.html
Colorado School of Mines	Constructed Wetlands	http://www.nttc.edu/env/site95/emrg/complete/colorado.html
CORNELL Composting	Composting	http://www.cfe.cornell.edu/compost/Composting_homepage.html
Ctr. for Hazardous Materials Research	Chemical Extraction	http://www.nttc.edu/env/site95/emrg/complete/chmracid.html
Current Environmental Solutions	Thermal Treatment	http://bigisland.ttclients.com/frtr/00000159.html

Current Environmental Solutions	Thermal Treatment	http://bigisland.ttclients.com/frtr/00000150.html
DENIX	Landfarming	http://denix.cecer.army.mil/denix/Public/Library/Remedy/LowryLF/lowryl01.html
DOE/ANL	Slurry Phase Biological Treatment	http://bigisland.ttclients.com/frtr/00000152.html
DOE/ANL	Phytoremediation	http://bigisland.ttclients.com/frtr/00000160.html
DOE/EM	In Situ Thermal Treatment for Soil, Sediment, and Sludge	http://ost.em.doe.gov/ifd/ost/pubs.htm
DOE/EM	Bioventing	http://eagle.emweb.icx.net/define/techs/rp-insit.html#321
DOE/EM	Fracturing	http://ost.em.doe.gov/pubs/itsrs/itsr163.pdf
DOE/EM	Solidification/ Stabilization (In situ)	
DOE/EM	Solidification/ Stabilization (In situ)	http://em-52.em.doe.gov/ifd/techcards1/scfa/insitu.htm
DOE/EM	Thermal Treatment	http://www.em.doe.gov/plumesfa/intech/spsh/sum.html
DOE/EM	Thermal Treatment	http://eagle.emweb.icx.net/define/techs/rp-insit.html#321
DOE/EM	Thermal Treatment	http://em-52.em.doe.gov/ifd/techcards1/scfa/sixphs.htm
DOE/EM	Thermal Treatment	http://em-52.em.doe.gov/ifd/techcards1/scfa/teves.htm
DOE/EM	Enhanced Biodegradation (In situ)	http://eagle.emweb.icx.net/define/techs/rp-insit.html#321
DOE/EM	Enhanced Biodegradation (In situ)	http://www.em.doe.gov/plumesfa/intech/enhanced/index.html
DOE/EM	Enhanced Biodegradation (In situ)	http://www.em.doe.gov/plumesfa/intech/isbuhw/index.html
DOE/EM	Enhanced Biodegradation (In situ)	http://em-52.em.doe.gov/ifd/techcards1/scfa/methenh.htm
DOE/EM	Solidification/ Stabilization (Ex	http://em-52.em.doe.gov/ifd/techcards2/mwfa/php.htm

	situ)	
DOE/EM	Solidification/ Stabilization (Ex situ)	http://em-52.em.doe.gov/ifd/techcards2/mwfa/polymacr.htm
DOE/EM	Solidification/ Stabilization (Ex situ)	http://em-52.em.doe.gov/ifd/techcards2/mwfa/tvs.htm
DOE/EM	Excavation, Retrieval, and Off-Site Disposal	http://eagle.emweb.icx.net/define/techs/rp-insit.html#321
DOE/EM	Natural Attenuation (Water)	http://eagle.emweb.icx.net/define/techs/rp-insit.html#321
DOE/EM	Air Sparging	http://eagle.emweb.icx.net/define/techs/rp-insit.html#321
DOE/EM	Air Sparging	http://em-52.em.doe.gov/ifd/techcards1/scfa/vapextr.htm
DOE/EM	Air Sparging	http://ost.em.doe.gov/tms/Home/Frameset.asp
DOE/EM	Directional Wells	http://www.em.doe.gov/plumesfa/intech/isasuhw/index.html
DOE/EM	Dual Phase Extraction	http://eagle.emweb.icx.net/define/techs/rp-insit.html#321
DOE/EM	Thermal Treatment	http://www.em.doe.gov/plumesfa/intech/dus/index.html
DOE/EM	Thermal Treatment	http://em-52.em.doe.gov/ifd/techcards1/scfa/dus.htm
DOE/EM	In-Well Air Stripping	http://www.em.doe.gov/plumesfa/intech/isasuhw/index.html
DOE/EM	Separation (Water)	http://em-52.em.doe.gov/ifd/techcards2/escc/tempvac.htm
DOE/EM	Separation (Water)	http://em-52.em.doe.gov/ifd/techcards2/scfa/lasagna.htm
DOE/EM	Ground Water Pumping	http://eagle.emweb.icx.net/define/techs/rp-insit.html#321
DOE/EM	Electrokinetic Separation	http://em-52.em.doe.gov/ifd/scfa/solutions/pfa29.htm
DOE/EM	Electrokinetic Separation	http://www.em.doe.gov/plumesfa/intech/lasagna/index.html
DOE/EM	Biofiltration	http://em-52.em.doe.gov/ifd/techcards1/scfa/biocube.htm
DOE/EM	Oxidation	http://www.em.doe.gov/plumesfa/intech/fto/index.html
DOE/EM	Fracturing	http://www.em.doe.gov/plumesfa/intech/lasagna/
DOE/EM	Soil Flushing	http://eagle.emweb.icx.net/define/techs/rp-insit.html#321
DOE/EM	Soil Vapor Extraction (In situ)	http://eagle.emweb.icx.net/define/techs/rp-insit.html#321
DOE/FETC	Incineration	http://www.fetc.doe.gov/products/power/fbc.html
DOE/GJO	Passive/Reactive Treatment Walls	http://www.clu-in.org/download/techdrct/tdpermeab2.pdf

DOE/INEL	Soil Vapor Extraction (In situ)	http://es.inel.gov/new/funding/serdp/fy93cm9.html
DOE/INEL	Bioreactors	http://www.inel.gov/capabilities/biotech/Explos.html
DOE/INEL	Bioreactors	http://www.inel.gov/capabilities/biotech/Hazwaste.html
DOE/INEL	Biofiltration	http://www.inel.gov/capabilities/biotech/Biofilt.html
DOE/LANL	Separation	http://bigisland.ttclients.com/frtr/00000182.html
DOE/LLNL	Thermal Treatment	http://www.llnl.gov/ees/aet/dynstrip/dynstrip.html
DOE/LLNL	Pyrolysis	http://www.llnl.gov/IPandC/op96/03/3h-mol.html
DOE/OIT	Phytoremediation	http://bwonotes5.wdc.pnl.gov/IOF.nsf/
DOE/ORNL	Bioventing	http://orcmt.oakridge.org/capabilities/dtin_lst.html
DOE/ORNL	Solidification/ Stabilization (In situ)	http://orcmt.oakridge.org/bmp/isvwaste.html
DOE/ORNL	Thermal Treatment	http://www.ornl.gov/K25/techdemo/insitu.htm
DOE/ORNL	Enhanced Biodegradation (In situ)	http://orcmt.oakridge.org/capabilities/dtin311.html
DOE/ORNL	Phytoremediation	http://orcmt.oakridge.org/capabilities/dtin_lst.html
DOE/ORNL	Electrokinetic Separation	http://www.ornl.gov/K25/techdemo/electro.htm
DOE/ORNL	Soil Washing	http://www.ornl.gov/K25/techdemo/soilwash.htm
DOE/ORNL	Solidification/ Stabilization (Ex situ)	http://www.ornl.gov/K25/techdemo/macencp.htm
DOE/ORNL	Solidification/ Stabilization (Ex situ)	http://www.ornl.gov/K25/techdemo/tvs.htm
DOE/ORNL	Excavation, Retrieval, and Off-Site Disposal	http://www.ornl.gov/K25/techdemo/boa.htm
DOE/ORNL	Advanced Oxidation Processes	http://www.ornl.gov/K25/techdemo/epasite.htm
DOE/PNNL	Chemical Reduction/Oxidation	http://bigisland.ttclients.com/frtr/00000212.html
DOE/PNNL	Chemical Reduction/Oxidation	http://bigisland.ttclients.com/frtr/00000216.html
DOE/PNNL	Chemical Reduction/Oxidation	http://bigisland.ttclients.com/frtr/00000209.html
DOE/PNNL	Enhanced Bioremediation	http://bigisland.ttclients.com/frtr/00000151.html
DOE/PNL	In-Well Air Stripping	http://www.pnl.gov/etd/stomp/application.html#edwards

DOE/PRNL	Constructed Wetlands	http://orcmt.oakridge.org/capabilities/dtin321.html
DOE/SCFA	Phytoremediation	http://www.envnet.org/scfa/prodlines/mr/factsheets/biomass.htm
DOE/SCFA	Fracturing	http://www.envnet.org/scfa/prodlines/dnapl/factsheets/tms4.pdf
DOE/SCFA	Solidification/ Stabilization	http://www.envnet.org/scfa/prodlines/stcr/factsheets/cement.htm
DOE/SCFA	Solidification/ Stabilization	http://www.envnet.org/scfa/prodlines/dnapl/factsheets/tms51.pdf
DOE/SCFA	Solidification/ Stabilization	http://www.envnet.org/scfa/archive/stc/godzilla.htm
DOE/SCFA	Solidification/ Stabilization	http://www.envnet.org/scfa/archive/str/insitu.htm
DOE/SCFA	Solidification/ Stabilization	http://www.envnet.org/scfa/archive/stc/jetgrout.htm
DOE/SCFA	Solidification/ Stabilization	http://www.envnet.org/scfa/prodlines/stcr/factsheets/visliq.pdf
DOE/SCFA	Chemical Extraction	http://www.envnet.org/scfa/prodlines/mr/factsheets/ curr%2Drrp.htm
DOE/SCFA	Landfill Cap	http://www.envnet.org/scfa/prodlines/stcr/factsheets/altland.pdf
DOE/SCFA	Landfill Cap Enhancements	http://www.envnet.org/scfa/archive/stc/capill.htm
DOE/SCFA	Phytoremediation of Organics	http://www.envnet.org/scfa/prodlines/mr/factsheets/biomass.pdf
DOE/SCFA	In-Well Air Stripping	http://www.envnet.org/scfa/prodlines/dnapl/factsheets/inwell.htm
DOE/SCFA	Passive/Reactive Treatment Walls	http://www.envnet.org/scfa/prodlines/dnapl/factsheets/ zero-valent.htm
DOE/SCFA	Passive/Reactive Treatment Walls	http://www.envnet.org/scfa/prodlines/mr/factsheets/tms46.pdf
DOE/SCFA	Precipitation/ Coagulation/ Flocculation	http://www.envnet.org/scfa/prodlines/mr/factsheets/curr-rrp.htm
DOE/SCFA	Separation (Water)	http://www.envnet.org/scfa/tech/mrr/factsheets/curr-rrp.htm
DOE/SNL	Electrokinetic Separation	http://bigisland.ttclients.com/frtr/00000173.html
DOE/SNL	Chemical Extraction	http://bigisland.ttclients.com/frtr/00000184.html
DOE/SNL	Separation	http://bigisland.ttclients.com/frtr/00000181.html
DOE/SNL	Landfill Cap	http://www.sandia.gov/Subsurface/factshts/ert/alcd.pdf
DOE/SNL	Landfill Cap	http://www.sandia.gov/Subsurface/factshts/ert/capbarr.pdf

DOE/SNL	Landfill Cap	http://www.sandia.gov/Subsurface/factshts/ert/drybarrier.pdf
DOE/SNL	Landfill Cap Enhancements	http://www.sandia.gov/Subsurface/factshts/ert/capbarr.pdf
DOE/SNL	Landfill Cap Enhancements	http://www.sandia.gov/Subsurface/factshts/ert/alcd.pdf
DOE/SNL	Landfill Cap Enhancements	http://www.sandia.gov/Subsurface/factshts/ert/drybarrier.pdf
DOE/SRS	Bioventing	http://www.srs.gov/general/sci-tech/environmental/BioPassVetConSoil.html
DOE/SRS	Bioventing	http://www.srs.gov/general/sci-tech/environmental/BioVentConSoil.html
DOE/SRS	Enhanced Biodegradation (In situ)	http://www.srs.gov/general/sci-tech/environmental/BioSanLandfillOptTest.html
DOE/SRS	Enhanced Biodegradation (In situ)	http://www.srs.gov/general/sci-tech/RD100/bio_rem1.html
DOE/SRS	Enhanced Biodegradation (In situ)	http://bigisland.ttclients.com/frtr/00000174.html
DOE/SRS	Enhanced Biodegradation (In situ)	http://bigisland.ttclients.com/frtr/00000201.html
DOE/SRS	Phytoremediation	http://www.srs.gov/general/sci-tech/environmental/BioMicrobVeg.html
DOE/SRS	Enhanced Bioremediation (Water)	http://www.srs.gov/general/sci-tech/RD100/bio_rem1.html
DOE/SRS	Phytoremediation of Organics	http://www.srs.gov/general/sci-tech/environmental/BioMicrobVeg.html
DOE/SRS	Bioreactors	http://www.srs.gov/general/sci-tech/environmental/BioEncap.html
DOE/SRS	Bioreactors	http://www.srs.gov/general/sci-tech/environmental/BioFldzdBedBioRx.html
DOE/SRS	Sprinkler Irrigation	http://www.srs.gov/general/sci-tech/environmental/BioMobTrikFiltr.html
DOE/SRS	Sprinkler Irrigation	http://www.srs.gov/general/sci-tech/environmental/BioUSAFTrk.html
DOE/SRS	Biofiltration	http://www.srs.gov/general/sci-tech/environmental/BioECOVAbioRx.html
DOI/USGS	Enhanced Biodegradation (In situ)	http://water.usgs.gov/public/wid/html/bioremed.html
DOI/USGS	Natural Attenuation (Water)	http://ak.water.usgs.gov/Publications/Abstracts/1998.Abstracts/aec_work_abs.htm
DuPont Engineering	Enhanced	http://bigisland.ttclients.com/frtr/00000144.html

	Bioremediation	
Dynaphore, Inc.	Adsorption/ Absorption	http://www.nttc.edu/env/site95/demo/complete/dynaphor.html
Earth Tech	Thermal Desorption	http://bigisland.ttclients.com/frtr/00000141.html
Edenspace Systems Corp.	Phytoremediation	http://bigisland.ttclients.com/frtr/00000164.html
E.I. DuPont de Nemours and Co.	Separation (Water)	http://www.nttc.edu/env/site95/demo/complete/dupont.html
Eckenfelder Inc	Soil Vapor Extraction (In situ)	
Eckenfelder Inc	Air Sparging	
Electrokinetics, Inc	Electrokinetic Separation	http://www.nttc.edu/env/site95/emrg/complete/electrok.html
Electrokinetics, Inc	Electrokinetic Separation	http://bigisland.ttclients.com/frtr/00000171.html
ELI Eco Logic International Inc.	Thermal Desorption	http://www.nttc.edu/env/site95/demo/complete/ecologtd.html
Energy & Environmental Research Corp.	Incineration	http://www.nttc.edu/env/site95/emrg/complete/eerc.html
ENSR	Bioslurping	http://www.ensr.com/newsroom/hazwaste.htm
USEPA	Enhanced Bioremediation	http://bigisland.ttclients.com/frtr/00000147.html
EPA/NSCEP	Enhanced Biodegradation (In situ)	http://clu-in.org/techpubs.htm
EPA/NSCEP	Incineration	http://clu-in.org/techpubs.htm
EPA/NSCEP	Thermal Desorption	http://clu-in.org/techpubs.htm
EPA/NSCEP	Enhanced Bioremediation (Water)	http://clu-in.org/techpubs.htm
EPA/NSCEP	Air Sparging	http://clu-in.org/techpubs.htm
EPA/NSCEP	Bioslurping	http://clu-in.org/techpubs.htm
EPA/NSCEP	Dual Phase Extraction	http://clu-in.org/techpubs.htm
EPA/NSCEP	In-Well Air Stripping	http://clu-in.org/techpubs.htm
EPA/NSCEP	Passive/Reactive Treatment Walls	http://clu-in.org/techpubs.htm
EPA/NSCEP	Oxidation	http://clu-in.org/techpubs.htm
EPA/NSCEP	Soil Flushing	http://clu-in.org/techpubs.htm
EPA/NSCEP	Solidification/ Stabilization	http://clu-in.org/techpubs.htm
EPA/NRMRL	Bioventing	http://www.epa.gov/ORD/NRMRL/lrpcd/tdb/
EPA/NRMRL	Composting	http://www.epa.gov/ORD/NRMRL/lrpcd/tdb/
EPA/NRMRL	Slurry Phase Biotreatment	http://www.epa.gov/ORD/NRMRL/lrpcd/tdb/

EPA/NRMRL	Soil Washing	http://www.epa.gov/ORD/NRMRL/lrpcd/tdb/
EPA/NRMRL	Incineration	http://www.epa.gov/docs/crb/aptb/rainbow.html
EPA/NRMRL	Incineration	http://www.epa.gov/docs/crb/aptb/dufbis.html
EPA/NRMRL	Incineration	http://www.epa.gov/docs/crb/aptb/mfc.html
EPA/NRMRL	Natural Attenuation (Water)	http://www.epa.gov/ada/pubs/reports.html
EPA/NRMRL	Natural Attenuation (Water)	http://www.clu-in.org/download/techdrct/tdnatmtbe.pdf
EPA/NRMRL	Phytoremediation of Organics	http://www.epa.gov/ORD/NRMRL/lrpcd/tdb/
EPA/NRMRL	Phytoremediation	http://www.epa.gov/ORD/NRMRL/lrpcd/tdb/
EPA/NRMRL	Biofiltration	http://www.epa.gov/ORD/NRMRL/lrpcd/tdb/
EPA/NRMRL	Passive/Reactive Treatment Walls	http://www.epa.gov/ada/pubs/reports.html
EPA/NRMRL/SPRD	Passive/Reactive Treatment Walls	http://www.rtdf.org/public/permbarr/barrdocs.htm
EPA/ORD	Enhanced Biodegradation (In situ)	http://www.epa.gov/ORD/SITE/reports
EPA/ORD	Phytoremediation	http://clu-in.org/techpubs.htm
EPA/ORD	Thermal Desorption	http://www.epa.gov/ORD/SITE/reports
EPA/ORD	Thermal Treatment	http://www.epa.gov/ORD/SITE/reports
EPA/ORD	Air Stripping	http://www.epa.gov/ORD/SITE/reports
EPA/ORD	Soil Flushing	http://www.epa.gov/ORD/SITE/reports
EPA/ORD	Soil Vapor Extraction (In situ)	http://www.epa.gov/ORD/SITE/reports
EPA/ORD	Solidification/ Stabilization	http://www.epa.gov/ORD/SITE/reports
EPA/OSWER	Natural Attenuation (Water)	http://www.epa.gov/swerffrr/chlorine.htm
EPA/OSWER	Air Sparging	http://www.clu-in.org/techdrct/techpubs.asp
EPA/OSWER	Phytoremediation	http://clu-in.org/techpubs.htm
EPA/OSWER	Soil Flushing	http://clu-in.org/techpubs.htm
EPA/OSWER	Thermal Treatment	http://www.clu-in.org/techdrct/techpubs.asp
EPA/OSWER	Composting	http://www.epa.gov/compost
EPA/OSWER	Passive/Reactive Treatment Walls	http://www.clu-in.org/techdrct/techpubs.asp
EPA/OUST	Bioventing	http://www.epa.gov/swerust1/cat/biovent.htm
EPA/OUST	Biopiles	http://www.epa.gov/swerust1/cat/biopiles.htm
EPA/OUST	Landfarming (Ex situ)	http://www.epa.gov/swerust1/cat/landfarm.htm

EPA/OUST	Thermal Desorption	http://www.epa.gov/swerust1/cat/lttd.htm
EPA/OUST	Land Treatment	http://www.epa.gov/swerust1/cat/landfarm.htm
EPA/OUST	Enhanced Bioremediation (Water)	http://www.epa.gov/swerust1/cat/insitbio.htm
EPA/OUST	Natural Attenuation (Water)	http://www.epa.gov/swerust1/cat/natatt.htm
EPA/OUST	Air Sparging	http://www.epa.gov/swerust1/cat/airsparg.htm
EPA/OUST	Dual Phase Extraction	http://www.epa.gov/swerust1/cat/dualphas.htm
EPA/OUST	Soil Vapor Extraction (In situ)	http://www.epa.gov/swerust1/cat/sve1.htm
EPA/ORD/NRMRL	Natural Attenuation (Water)	http://www.clu-in.org/techdrct/techpubs.asp
EPA/TIO	Enhanced Biodegradation (In situ)	http://clu-in.org/techpubs.htm
EPA/TIO	Enhanced Biodegradation (In situ)	http://clu-in.org/techfocus/
EPA/TIO	Enhanced Biodegradation (In situ)	http://www.epa.gov/swertio1/products/citguide/default.htm
EPA/TIO	Dehalogenation	http://www.epa.gov/swertio1/products/citguide/dehalo.htm
EPA/TIO	Soil Washing	http://www.epa.gov/swertio1/products/citguide/soilwash.htm
EPA/TIO	Pyrolysis	http://www.clu-in.org/techpubs.htm
EPA/TIO	Thermal Desorption	http://clu-in.org/techfocus/
EPA/TIO	Enhanced Bioremediation (Water)	http://clu-in.org/techpubs.htm
EPA/TIO	Enhanced Bioremediation (Water)	http://clu-in.org/techfocus/
EPA/TIO	Natural Attenuation (Water)	http://www.epa.gov/ORD/WebPubs/biorem/D9200417.pdf
EPA/TIO	Natural Attenuation (Water)	http://clu-in.org/techfocus/
EPA/TIO	Air Sparging	http://clu-in.org/techpubs.htm
EPA/TIO	Air Sparging	http://clu-in.org/techfocus/

EPA/TIO	Air Sparging	http://www.epa.gov/swertio1/products/citguide/sve.htm
EPA/TIO	Directional Wells	http://clu-in.org/techdrct/techpubs.htm
EPA/TIO	Dual Phase Extraction	http://clu-in.org/techpubs.htm
EPA/TIO	Dual Phase Extraction	http://clu-in.org/techfocus/
EPA/TIO	Passive/Reactive Treatment Walls	http://clu-in.org/techpubs.htm
EPA/TIO	Passive/Reactive Treatment Walls	http://www.epa.gov/ORD/SITE/reports/r98501.html
EPA/TIO	Passive/Reactive Treatment Walls	http://clu-in.org/techfocus/
EPA/TIO	Passive/Reactive Treatment Walls	http://www.epa.gov/swertio1/products/citguide/default.htm
EPA/TIO	Phytoremediation	http://clu-in.org/techfocus/
EPA/TIO	Ground Water Pumping	http://www.clu-in.org/techpubs.htm
EPA/TIO	Electrokinetic Separation	http://www.epa.gov/swertio1/products/moreinfo/iselectr.htm
EPA/TIO	Oxidation	http://clu-in.org/techfocus/
EPA/TIO	Fracturing	http://clu-in.org/techfocus/
EPA/TIO	Fracturing	http://www.epa.gov/swertio1/images/hydro.gif
EPA/TIO	Fracturing	http://www.epa.gov/swertio1/images/pneu.gif
EPA/TIO	Soil Flushing	http://clu-in.org/techpubs.htm
EPA/TIO	Soil Flushing	http://clu-in.org/techfocus/
EPA/TIO	Soil Flushing	http://www.epa.gov/swertio1/images/surcos.gif
EPA/TIO	Soil Flushing	http://www.epa.gov/swertio1/products/citguide/soilflsh.htm
EPA/TIO	Soil Flushing	http://www.epa.gov/swertio1/products/citguide/solvextr.htm
EPA/TIO	Soil Vapor Extraction (In situ)	http://clu-in.org/techfocus/
EPA/TIO	Soil Vapor Extraction (In situ)	http://www.epa.gov/swertio1/products/citguide/sve.htm
EPA/TIO	Soil Vapor Extraction (In situ)	http://www.epa.gov/swertio1/images/therenh.gif

USEPA	Bioventing	http://bigisland.ttclients.com/frtr/00000162.html
ESTCP	Bioventing	http://www.estcp.org/projects/cleanup/199715o.cfm
ESTCP	Enhanced Biodegradation (In situ)	http://www.estcp.org/documents/techdocs/index.cfm
ESTCP	Slurry Phase Biological Treatment	http://www.estcp.org/projects/cleanup/199512o.cfm
ESTCP	Chemical Reduction/Oxidation	http://www.estcp.org/technical_documents.htm
ESTCP	Separation	http://estcp.xservices.com/projects/comply/199805.htm
ESTCP	Enhanced Bioremediation (Water)	http://www.estcp.org/documents/techdocs/index.cfm
ESTCP	Enhanced Bioremediation (Water)	http://estcp.xservices.com/projects/comply/199710.htm
ESTCP	Natural Attenuation (Water)	http://www.estcp.org/projects/cleanup/199518v.cfm
ESTCP	Natural Attenuation (Water)	http://www.wes.army.mil/el/elpubs/pdf/trel99-7.pdf
ESTCP	Phytoremediation of Organics	http://www.estcp.org/projects/cleanup/
ESTCP	Air Sparging	http://www.estcp.org/projects/cleanup/199808o.cfm
ESTCP	Air Sparging	http://www.estcp.org/projects/cleanup/199808o.cfm
ESTCP	Passive/Reactive Treatment Walls	http://estcp.xservices.com/projects/cleanup/remed/199604.htm
ESTCP	Passive/Reactive Treatment Walls	http://www.estcp.org/technical_documents.htm
ESTCP	Phytoremediation	http://estcp.xservices.com/projects/cleanup/remed/199809.htm
ESTCP	Phytoremediation	http://www.estcp.org/projects/cleanup/
ESTCP	Phytoremediation	http://www.estcp.org/technical_documents.htm
ESTCP	Separation	http://estcp.xservices.com/projects/pollutn/199705.htm
ESTCP	Separation	http://www.estcp.org/projects/pollutn/verif/199501v.htm
ESTCP	Electrokinetic Separation	http://www.estcp.org/projects/cleanup/199605o.cfm
General Atomics	Incineration	http://www.nttc.edu/env/site95/demo/complete/genatom.html
Geo-Cleanse International, Inc.	Oxidation	http://bigisland.ttclients.com/frtr/00000210.html
Geo-Cleanse International, Inc.	Oxidation	http://bigisland.ttclients.com/frtr/00000168.html

Geo-Con, Inc.	Solidification/ Stabilization	http://www.nttc.edu/env/site95/demo/complete/geo-con.html
Geo-Con, Inc.	Landfill Cap	http://www.geocon.net/overview_of_technologies.htm
Geo-Con, Inc.	Passive/Reactive Treatment Walls	http://www.geocon.net/overview_of_technologies.htm
Geo-Con, Inc.	Constructed Wetlands	http://www.geocon.net/overview_of_technologies.htm
Geo-Con, Inc.	Physical/Biological Barriers	http://www.geocon.net/overview_of_technologies.htm
Geokinetics International	Electrokinetic Separation	http://www.geokinetics.com/
Geosafe Corporation	Solidification/ Stabilization	http://www.nttc.edu/env/site95/demo/complete/geosafe.html
Global Network Environmental Tech.	Bioslurping	http://www.gnet.org/archive/4527.html
Global Network Environmental Tech.	Passive/Reactive Treatment Walls	http://www.gnet.org/archive/20122.html
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Thermal Treatment	http://www.gwrtac.org/html/tech_status.html#THERMAL
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Phytoremediation of Organics	http://www.gwrtac.org/html/tech_over.html#PHYTOREM
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Air Sparging	http://www.gwrtac.org/html/tech_over.html#AIRSPAR
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Bioslurping	http://www.gwrtac.org/html/tech_over.html#BIOSLURB
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Directional Wells	http://www.gwrtac.org/html/tech_over.html#HORIZWELL
Ground Water Remediation Technologies Analysis	In-Well Air Stripping	http://www.gwrtac.org/html/tech_over.html#INWELL

Center (GWRTAC)		
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Passive/Reactive Treatment Walls	http://www.gwrtac.org/html/tech_eval.html#TWALLS
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Passive/Reactive Treatment Walls	http://www.gwrtac.org/html/tech_status.html#WALLS
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Phytoremediation	http://www.gwrtac.org/html/tech_over.html#PHYTOREM
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Advanced Oxidation Processes	http://www.gwrtac.org/html/tech_over.html#UVOXID
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Ground Water Pumping	http://www.gwrtac.org/html/tech_eval.html#SURF
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Electrokinetic Separation	http://www.gwrtac.org/html/tech_status.html#ELECTRO
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Fracturing	http://www.gwrtac.org/html/tech_status.html#FRACT
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Fracturing	http://www.gwrtac.org/html/tech_over.html#BLAST
Ground Water Remediation Technologies Analysis Center (GWRTAC)	Soil Flushing	http://www.gwrtac.org/html/tech_status.html#COSOLV

Ground Water Remediation Technologies Analysis Center (GWRTAC)	Soil Flushing	http://www.gwrtac.org/pdf/inchem.pdf
Gruppo Italimpresse	Incineration	http://www.nttc.edu/env/site95/demo/complete/gruppoit.html
GZA GeoEnvironmental, Inc.	Enhanced Biodegradation	http://www.gza.net/bioremediation/bioremediation.asp
GZA GeoEnvironmental, Inc.	Enhanced Bioremediation	http://www.gza.net/bioremediation/bioremediation.asp
Hazardous Substance Management Res	Fracturing	http://www.nttc.edu/env/site95/emrg/complete/hazard.html
Hill AFB	Bioventing	http://137.241.156.3/esoh/Biofact.pdf
IIT Research Institute/ Brown & Root	Thermal Treatment	http://www.nttc.edu/env/site95/demo/complete/iit.html
Ionics/Resources Conservation Co.	Chemical Extraction	http://www.nttc.edu/env/site95/demo/complete/ionics.html
Interstate Technology and Regulatory Cooperation (ITRC) Work Group	Enhanced Bioremediation (Water)	http://clu-in.org/techpubs.htm
Interstate Technology and Regulatory Cooperation (ITRC) Work Group	Phytoremediation	http://clu-in.org/techpubs.htm
Interstate Technology and Regulatory Cooperation (ITRC) Work Group, and the Remediation Technologies Development Forum (RTDF)	Natural Attenuation (Water)	http://clu-in.org/conf/itrc/natatt/p&p.pdf
KAI Technologies, Inc./Brown & Root	Thermal Treatment	http://www.nttc.edu/env/site95/demo/complete/kaitech.html
Kansas State University	Phytoremediation	http://www.engg.ksu.edu/HSRC/phytorem/
Kelchner	Solidification/ Stabilization	http://www.kelchner.com/stabil.htm
Kelchner	Enhanced Biodegradation	http://www.kelchner.com/gwater.htm
Kelchner	Landfill Cap	http://www.kelchner.com/hdpe.htm

Kelchner	Excavation, Retrieval, and Off-Site Disposal	http://www.kelchner.com/excavate.htm
Lynntech, Inc.	Electrokinetic Separation	http://bigisland.ttclients.com/frtr/00000170.html
Matrix Photocatalytic, Inc.	Oxidation	http://www.nttc.edu/env/site95/emrg/complete/matrixti.html
Maxymillian Technologies	Thermal Desorption	http://www.nttc.edu/env/site95/demo/complete/maxymill.html
McLaren/Hart, Inc	Thermal Desorption	http://bigisland.ttclients.com/frtr/00000220.html
McClellan AFB	Dual Phase Extraction	https://www.mcclellan.af.mil/EM/Ntsit/DEMOS/multiphase.html
McClellan AFB	High Energy Destruction	https://www.mcclellan.af.mil/EM/Ntsit/DEMOS/sdp_netts.html
McClellan AFB	Oxidation	https://www.mcclellan.af.mil/EM/Ntsit/DEMOS/fto.html
Metcalf & Eddy	Air Stripping	http://www.m-e.com/site/rem1.htm
N.Y. State Dept. of Envir. Cons/ENSR	Bioventing	http://www.nttc.edu/env/site95/demo/complete/nyrew.html
National Technology Transfer Center (NTTC)	Electrokinetic Separation	http://iridium.nttc.edu/env/tmp/008.html
NDCEE	Ion Exchange	http://www.ndcee.ctc.com/b4.html
NDCEE	Separation	http://www.ndcee.ctc.com/b4.html
NDCEE	Separation	http://www.ndcee.ctc.com/b4.html
NDCEE	Separation	http://www.ndcee.ctc.com/b4.html
NDCEE	Separation	http://www.ndcee.ctc.com/b4.html
NDCEE	Separation	http://www.ndcee.ctc.com/b4.html
NFESC	Enhanced Biodegradation	http://enviro.nfesc.navy.mil/esc414/techinfo/shortlist/matrix.htm
NFESC	Thermal Treatment	http://enviro.nfesc.navy.mil/ps/projects/sive.htm
NFESC	Biopiles	http://enviro.nfesc.navy.mil/ps/projects/heap.htm
NFESC	Slurry Phase Biological Treatment	http://enviro.nfesc.navy.mil/ps/projects/ordncbio.htm
NFESC	Dehalogenation	http://www.nfesc.navy.mil/enviro/ps/projects/bcdp.htm
NFESC	Thermal Desorption	http://enviro.nfesc.navy.mil/ps/projects/thermdes.htm
NFESC	Landfill Cap	http://enviro.nfesc.navy.mil/ps/projects/landfill.htm
NFESC	Landfill Cap Enhancements	http://www.nfesc.navy.mil/enviro/ps/projects/landfill.htm
	Enhanced	

NFESC	Bioremediation (Water)	http://enviro.nfesc.navy.mil/esc414/techinfo/shortlist/matrix.htm
NFESC	Enhanced Bioremediation	http://bigisland.ttclients.com/frtr/00000215.html
NFESC	Bioslurping	http://www.nfesc.navy.mil/enviro/ps/projects/bioslurp.htm
NFESC	Thermal Treatment	http://www.nfesc.navy.mil/enviro/ps/projects/sive.htm
NFESC	Passive/Reactive Treatment Walls	http://www.nfesc.navy.mil/enviro/ps/projects/permeabl.htm
NFESC	Constructed Wetlands	http://enviro.nfesc.navy.mil/ps/projects/cnwthom.htm
NFESC	GAC /Liquid Phase Carbon Adsorption	http://enviro.nfesc.navy.mil/p2library/cgi-bin/p2h_datasheet.cfm?itemID=220
NFESC	Advanced Oxidation Processes	http://www.nfesc.navy.mil/enviro/ps/projects/photoche.htm
NFESC	Ground Water Pumping	http://enviro.nfesc.navy.mil/ps/sear/sear.htm
OHM Remediation Services Corp.	Thermal Desorption	http://www.nttc.edu/env/site95/demo/complete/ohm.html
Parsons Engineering Science, Inc.	Natural Attenuation	http://bigisland.ttclients.com/frtr/00000166.html
Parsons Engineering Science, Inc.	Natural Attenuation	http://bigisland.ttclients.com/frtr/00000167.html
Porocel Corporation	Adsorption/ Absorption	http://www.porocel.com/
Radian International LLC	Thermal Desorption	http://bigisland.ttclients.com/frtr/00000153.html
Radian International LLC	Passive/Reactive Treatment Walls	http://bigisland.ttclients.com/frtr/00000142.html
Remediation Services, Int'l	Air Sparging	http://www.rsi-save.com
Remediation Services, Int'l	Ground Water Pumping	http://www.rsi-save.com
Remediation Services, Int'l	Oxidation	http://www.rsi-save.com
Remediation Services, Int'l	Soil Vapor Extraction (In situ)	http://www.rsi-save.com
Remediation Technologies, Inc.	Oxidation	http://www.nttc.edu/env/site95/emrg/complete/remediat.html
Remediation Technologies Development Forum (RTDF)	Enhanced Biodegradation	http://www.rtdf.org/bioremed.htm

Remediation Technologies Development Forum (RTDF)	Phytoremediation	http://www.rtdf.org/phyto.htm
Remediation Technologies Development Forum (RTDF)	Soil Flushing	http://www.rtdf.org/flushing.htm
Remediation Technologies Development Forum (RTDF)	Phytoremediation of Organics	http://www.rtdf.org/phyto.htm
Remediation Technologies Development Forum (RTDF)	Phytoremediation of Organics	http://www.RTDF.org/public/phyto/protocol/protocol99.htm
Remediation Technologies Development Forum (RTDF)	Passive/Reactive Treatment Walls	http://www.rtdf.org/barriers.htm
Roy F. Weston, Inc.	Enhanced Bioremediation	http://bigisland.ttclients.com/frtr/00000146.html
RT Environmental Services, Inc.	Soil Vapor Extraction (In Situ)	http://bigisland.ttclients.com/frtr/00000169.html
SBP Technologies, Inc.	Separation (Water)	http://www.nttc.edu/env/site95/demo/complete/sbp.html
Smith Environmental Technologies Corporation	Thermal Desorption	http://bigisland.ttclients.com/frtr/00000161.html
Soliditech, Inc.	Solidification/ Stabilization (Ex situ)	http://www.nttc.edu/env/site95/demo/complete/solidite.html
SteamTech Environmental Services	Thermal Treatment	http://www.steamtech.com/SER.htm
SteamTech Environmental Services	Thermal Treatment	http://bigisland.ttclients.com/frtr/00000207.html
State University of New York at Oswego	Chemical Reduction/Oxidation	http://www.frtr.gov/matrix2/section4/ Electrochemical Peroxidation.html
Stone & Webster	Natural Attenuation	http://bigisland.ttclients.com/frtr/00000148.html

Environmental		
Svedala Industries, Inc.	Incineration	http://www.nttc.edu/env/site95/emrg/complete/svedala.html
TC Remediation, Div. of Omega Env. Inc	Solidification/ Stabilization (Ex situ)	http://www.nttc.edu/env/site95/demo/complete/stc.html
Terra-Kleen Response Group, Inc.	Solidification/ Stabilization (Ex situ)	http://www.nttc.edu/env/site95/demo/complete/terrakln.html
TerraVac	Bioventing	http://www.terravac.com/toolsbv.htm
TerraVac	Thermal Treatment	http://www.terravac.com/toolsve.htm
TerraVac	Air Sparging	http://www.terravac.com/toolas.htm
TerraVac	Fracturing	http://www.terravac.com/toolspsf.htm
TerraVac	Soil Vapor Extraction (In situ)	http://www.terravac.com/toolsve.htm
TerraVac	Dual Phase Extraction	http://bigisland.ttclients.com/frtr/00000176.html
Ultrox, A Div. of Zimpro Envir., Inc.	Advanced Oxidation Processes	http://www.nttc.edu/env/site95/demo/complete/ultrox.html
University of Dayton Research Institute	Solar Detoxification	http://www.nttc.edu/env/site95/emrg/ongoing/udayton.html
University of Florida, Solar Energy and Energy Conversion Laboratory(SEECL)	Solar Detoxification	http://www.me.ufl.edu/SOLAR/research.htm
University of Waterloo	Phytoremediation of Organics	http://clu-in.org
USACE	Bioventing	http://www.crrel.usace.army.mil/valliere/factsheets/Cat_O2.html
USACE	Bioventing	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Solidification/ Stabilization (In situ)	http://owww.cecer.army.mil/facts/sheets/LL07.html
USACE	Solidification/ Stabilization (In situ)	http://www.crrel.usace.army.mil/valliere/factsheets/Cat_O2.html
USACE	Thermal Treatment	http://hq.environmental.usace.army.mil/tools/it/it.html
USACE	Thermal Treatment	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm

USACE	Landfarming (Ex situ)	http://www.crrel.usace.army.mil/techpub/factsheets/O2-Environmental_Cleanup/O03.pdf
USACE	Landfarming (Ex situ)	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Enhanced Biodegradation (In situ)	http://www.mrd.usace.army.mil/mrded-h/intech.html
USACE	Enhanced Biodegradation (In situ)	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Chemical Reduction/Oxidation	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Chemical Reduction/Oxidation	http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html
USACE	Soil Washing	http://www.mrd.usace.army.mil/mrded-h/intech.html
USACE	Soil Washing	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Solidification/ Stabilization (Ex situ)	http://owww.cecer.army.mil/facts/sheets/UL37.html
USACE	Solidification/ Stabilization (Ex situ)	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Open Burn/Open Detonation	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Thermal Desorption	http://www.mrd.usace.army.mil/mrded-h/intech.html
USACE	Thermal Desorption	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Landfill Cap	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Excavation, Retrieval, and Off-Site Disposal	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Phytoremediation of Organics	http://www.wes.army.mil/el/phyto/
USACE	Air Sparging	http://www.mrd.usace.army.mil/mrded-h/intech.html
USACE	Air Sparging	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Air Sparging	http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html
USACE	Directional Wells	http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html

USACE	Dual Phase Extraction	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4010/toc.htm
USACE	Dual Phase Extraction	http://bigisland.ttclients.com/frtr/00000126.html
USACE	Phytoremediation	http://www.crrel.usace.army.mil/valliere/factsheets/Cat_O2.html
USACE	Phytoremediation	http://www.wes.army.mil/el/phyto/
USACE	Composting	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Ground Water Pumping	http://bigisland.ttclients.com/frtr/00000149.html
USACE	Passive/Reactive Treatment Walls	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Air Stripping	http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html
USACE	GAC /Liquid Phase Carbon Adsorption	http://owww.cecer.army.mil/facts/sheets/UL20.html
USACE	GAC /Liquid Phase Carbon Adsorption	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	GAC /Liquid Phase Carbon Adsorption	http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html
USACE	Ion Exchange	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Precipitation/ Coagulation/ Flocculation	http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html
USACE	Separation (Water)	http://www.crrel.usace.army.mil/valliere/factsheets/Cat_O2.html
USACE	Separation (Water)	http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html
USACE	Advanced Oxidation Processes	http://www.mrd.usace.army.mil/mrded-h/intech.html
USACE	Biofiltration	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Vapor Phase Carbon Adsorption	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Soil Vapor Extraction (In situ)	http://www.nws.usace.army.mil/geotech/lf4/lf4.htm
USACE	Bioreactors	http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-1-4007/toc.htm
USACE	Adsorption/ Absorption	http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html

USACE	Oxidation	http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html
USAEC	Bioventing	http://aec-www.apgea.army.mil:8080/prod/usaec/op/update/fall96/biovent.htm
USAEC	Bioventing	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/pol03.htm
USAEC	Enhanced Biodegradation (In situ)	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/biorem.htm
USAEC	Composting	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/nitrocel.htm
USAEC	Composting	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/windrow.htm
USAEC	Composting	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/cstdsgn0.htm
USAEC	Composting	http://aec.army.mil/prod/usaec/et/mssg_31.htm#NGB
USAEC	Slurry Phase Biological Treatment	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/cstdsgn0.htm
USAEC	Slurry Phase Biological Treatment	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/soil.htm
USAEC	Slurry Phase Biological Treatment	http://aec-www.apgea.army.mil:8080/prod/usaec/op/update/spr97/bioslurr.htm
USAEC	Slurry Phase Biological Treatment	http://aec.army.mil/prod/files/lab.pdf
USAEC	Hot Gas Decontamination	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/hotgas.htm
USAEC	Natural Attenuation (Water)	http://aec-www.apgea.army.mil:8080/prod/usaec/er/natatten.htm
USAEC	Phytoremediation of Organics	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/phyto_01.htm
USAEC	Phytoremediation of Organics	http://aec-www.apgea.army.mil:8080/prod/usaec/op/update/jan96/plants.htm
USAEC	Phytoremediation of Organics	http://aec-www.apgea.army.mil:8080/prod/usaec/op/update/sum97/poplar.htm
USAEC	Phytoremediation of Organics	http://aec-www.apgea.army.mil:8080/prod/usaec/op/update/win97/iowa.htm
USAEC	Phytoremediation	http://aec-www.apgea.army.mil:8080/prod/usaec/op/update/jan96/plants.htm
USAEC	Phytoremediation	http://aec.army.mil/prod/usaec/et/restor/phyto_01.htm
USAEC	Phytoremediation	http://aec-www.apgea.army.mil:8080/prod/usaec/op/

		update/sum97/poplar.htm
USAEC	Phytoremediation	http://aec-www.apgea.army.mil:8080/prod/usaec/op/update/win97/iowa.htm
USAEC	Phytoremediation	http://www.estcp.org/projects/cleanup/
USAEC	Phytoremediation	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/phyremld.htm
USAEC	Phytoremediation	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/plantupt.htm
USAEC	Phytoremediation	http://bigisland.ttclients.com/frtr/00000154.html
USAEC	Separation	http://aec.army.mil/prod/usaec/et/pp/oil_water.htm
USAEC	Advanced Oxidation Processes	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/uvox.htm
USAEC	Electrokinetic Separation	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/insitu.htm
USAEC	Solidification/ Stabilization	http://aec.army.mil/prod/usaec/et/mssg_30.htm#MACOM01
USAEC	Landfarming (Ex situ)	http://aec.army.mil/prod/usaec/et/mssg_30.htm#MACOM02
USAEC	Phytoremediation	http://bigisland.ttclients.com/frtr/00000175.html
USAEC	Biofiltration	http://aec-www.apgea.army.mil:8080/prod/usaec/et/restor/trclet01.htm
USEPA	Passive/Reactive Treatment Walls	http://bigisland.ttclients.com/frtr/00000165.html
USEPA	Passive/Reactive Treatment Walls	http://bigisland.ttclients.com/frtr/00000206.html
Vortec Corporation	Solidification/ Stabilization	http://www.nttc.edu/env/site95/emrg/complete/vortec.html
Vulcan Peroxidation Systems, Inc.	Advanced Oxidation Processes	http://www.nttc.edu/env/site95/demo/complete/vulcan.html
WasTech, Inc.	Solidification/ Stabilization (Ex situ)	http://www.nttc.edu/env/site95/demo/complete/wastech.html
Zenon Environmental Inc.	Separation (Water)	http://www.nttc.edu/env/site95/demo/complete/zenoncfp.html

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Remediation Technologies Screening Matrix and Reference Guide, Version 4.0

Appendix A

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About EPA REACH IT

EPA REACH IT is a system that lets environmental professionals use the power of the Internet to search, view, download and print information about innovative remediation and characterization technologies. As of January 15, 2002, EPA REACH IT contains information about:

Remediation Technologies

- 656 technology vendors
- 1,289 technologies
- 1,688 sites at which remediation technologies have been applied

Characterization Technologies

- 42 technology vendors
- 181 technologies
- 253 sites at which characterization technologies have been applied

EPA REACH IT gives users access to comprehensive information about treatment and characterization technologies and their applications. It combines information submitted by technology service providers about remediation and characterization technologies with information from EPA, the U.S. Department of Defense (DoD), the U.S. Department of Energy (DOE), and state project mangers about sites at which innovative technologies are being deployed. Those sources together provide you with up-to-date information, not only about technologies you can use to characterize or remediate a site, but also about sites at which those technologies are being used and the service providers that offer them.

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Appendix B: DOE Site Remediation Technologies by Waste Contaminant Matrix and Completed Site Demonstration Program Projects as of December 1996

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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-0235) to provide a complete listing of the technology information presented in that document. 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, Ninth Edition (Document No. EPA/540/R-97/502). 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.

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Appendix C Table of Contents: Federal Data Bases and Additional Information Sources

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INTRODUCTION

Table C-1: System Characteristics of Federal Data Bases

Table C-2: Summary Table of Federal Databases

FEDERAL DATA BASES

Bioremediation in the Field Search System (BFSS)
Cleanup Information Bulletin Board System (CLU-IN)
Defense Environmental Network Information Exchange (DENIX)
Defense RDT&E Online System (DROLS)
Energy Science and Technology Data Base
Environmental Technologies Remedial Actions Data Exchange (EnviroTRADE)
Global Network for Environmental Technology (GNET)
Hazardous Waste Superfund Collection Data Base (HWSFD)
National Technical Information Service (NTIS) Bibliographic Data Base
New Technology from DOE (NTD)
Prospective Technology (PROTECH) and the Technology Catalogue
Records of Decision System (RODS)
REOPT: Electronic Encyclopedia of Remedial Action Options
Research in Progress (RIP) Data Base
NRMRL Treatability Data Base
Soil Transport and Fate Data Base
Waste Management Information System

ADDITIONAL INFORMATION SOURCES

U.S. Army Hotline
Center for Environmental Research Information (CERI)
Defense Technical Information Center (DTIC)
Government Printing Office (GPO)
National Center for Environmental Publications and Information
National Technical Information Service (NTIS)
Office of Research and Development Electronic Bulletin Board System (ORD BBS)
Public Information Center (PIC)
Technology Transfer Publications

Table C-3: Summary of Federal Site Remediation Technology Programs and Initiatives

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Appendix D Factors Affecting Treatment Cost and Performance

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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 Table D-1 and Table 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.

The measurement procedures and potential effects on treatment cost or performance for matrix characteristics and technology operation are shown in Table D-3 and Table D-4, respectively. These tables also indicate whether documentation is important for the listed measurement procedures.

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Appendix E Description of Source Documents

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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)	Environmental Quality Technology Demonstration, Evaluation and Transfer Activities, Annual Report, USAEC, 2000
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, Fourth Edition, October 1995 Federal Publications on Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation, Fourth Edition, October 1995 FRTR Remediation Technologies Screening Matrix and Reference Guide, Version III, November 1997
EPA	The Superfund Innovative Technology Evaluation (SITE) Program: Technology Profiles, Tenth Edition, 1999
DOE	Technology Catalogue, Second Edition, April 1995
USAF	Remedial Technology Design, Performance, and Cost Study, July 1992
California Military Environmental Coordination Committee	Treatment Technologies Applications Matrix for Base Closure Activities, Spring 1996
EPA/U.S. Navy	EPA/Navy CERCLA Remedial Action Technology Guide, November 1993

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Synonym List

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N | O | P | Q | R | S | T | U | V | W | X | Y | Z

Technology/Synonym	Go To
Absorption	Adsorption/Absorption
Acid Extraction	Chemical Extraction
Activated Alumina	Adsorption/Absorption
Activated Carbon	Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption
Adsorption/Absorption	Adsorption/Absorption
Aeration	Aeration
Air Sparging	Air Sparging
Air Stripping	Air Stripping
Alkali Metal/Polyethylene Glycol (APEG)	Dehalogenation
Asphalt/Concrete Cap	Landfill Cap
Base-Catalyzed Decomposition Process	Dehalogenation
Bioattenuation	Natural Attenuation
Bioaugmentation (for soil)	Enhanced Biodradation
Bioaugmentation (for water)	Enhanced Biodegradation
Biodegradation, Enhanced In Situ Water	Enhanced Biodegradation
Biofiltration	Biofiltration
Bioheaps	Biopiles

Biomounds	Biopiles
Biopiles	Biopiles
Bioreactors	Bioreactors
Bioslurping	Bioslurping
Bio-Slurry	Slurry Phase Biological Treatment
Biostimulation (for water)	Enhanced Biodegradation
Biostimulation (for soil)	Enhanced Biodegradation
Bioventing	Bioventing
Bituminization	Solidification/Stabilization
Blast-Enhanced Fracturing	Fracturing
Brackish Water Constructed Wetlands	Constructed Wetlands

TOP

Technology/Synonym	Go To
Cap	Landfill Cap
Carbon Filtration	Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption
Catalytic Oxidation	Oxidation
Chemical Extraction	Chemical Extraction
Chemical Reduction/Oxidation	Chemical Reduction/Oxidation
Circulating Bed Combustor	Incineration
Circulating Wells	Directional Wells (enhancement)
Class I Injection Wells	Deep Well Injection
Coagulation	Precipitation/Coagulation/Flocculation
Co-Metabolic Treatment	Co-Metabolic Treatment
Compost Piles	Biopiles
Composting	Composting

Constructed Wetlands	Constructed Wetlands
Controlled Solid-Phase Biological Treatment	Biopiles
Cosolvent Enhanced Soil Flushing	Soil Flushing
Deep Well Injection	Deep Well Injection
Dehalogenation	Dehalogenation
DSERT Code - D1	Incineration
DSERT Code - E0	Excavation, Retrieval, and Off-Site Disposal
DSERT Code - E1	Excavation, Retrieval, and Off-Site Disposal
DSERT Code - F11	Enhanced Biodegradation
DSERT Code - F12	Dual Phase Extraction
DSERT Code - F13	Dual Phase Extraction
DSERT Code - F14	Air Sparging
DSERT Code - F15	Hot Water or Steam Flushing/Stripping
DSERT Code - F16	Passive/Reactive Treatment Walls
DSERT Code - F17	Hydrofracturing
DSERT Code - F18	Bioreactors
DSERT Code - F19	Air Stripping
DSERT Code - F20	Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption
DSERT Code - F20	Vapor-Phase Carbon Adsorption
DSERT Code - F21	Ultraviolet Oxidation
DSERT Code - F21	Oxidation
DSERT Code - F3	Natural Attenuation
DSERT Code - F3	Natural Attenuation
DSERT Code - H1	Enhanced Bioremediation
DSERT Code - H1	Enhanced Biodegradation

DSERT Code - H11	Bioventing
DSERT Code - H12	Enhanced Bioremediation
DSERT Code - H12	Enhanced Biodegradation
DSERT Code - H14	Biopiles
DSERT Code - H15	Landfarming
DSERT Code - H15	Landfarming
DSERT Code - H16	Composting
DSERT Code - I2	Slurry Walls
DSERT Code - M11	Soil Vapor Extraction
DSERT Code - M11	Soil Vapor Extraction
DSERT Code - M12	Soil Flushing
DSERT Code - M13	Solidification/Stabilization
DSERT Code - M14	Soil Vapor Extraction, Thermally Enhanced
DSERT Code - M15	Fracturing
DSERT Code - N11	Solidification/Stabilization
DSERT Code - N12	Thermal Desorption
DSERT Code - N13	Chemical Reduction/Oxidation
DSERT Code - N14	Dehalogenation
DSERT Code - N15	Soil Washing
DSERT Code - N16	Chemical Extraction
DSERT Code - N17	Chemical Extraction
DSERT Code - Q1	Ground Water Pumping (for containment)
DSERT Code - R1	Excavation, Retrieval, and Off-Site Disposal
DSERT Code - S1	Excavation, Retrieval, and Off-Site Disposal
Directional Wells	Directional Wells (enhancement)

Distillation	Separation
Drawdown Pumping	Ground Water Pumping (for containment)
Dual Phase Extraction	Dual Phase Extraction

TOP

Technology/Synonym	Go To
Electrokinetic Separation	Electrokinetic Separation
Electrokinetics	Electrokinetic Separation
Electromagnetic Heat Enhanced SVE	Soil Vapor Extraction, Thermally Enhanced
Electromigration	Electrokinetic Separation
Emulsified Asphalt	Solidification/Stabilization
Enhanced Biodegradation, Aerobic	Enhanced Biodegradation
Enhanced Biodegradation, Aerobic In Situ	Enhanced Biodegradation
Enhanced Biodegradation, Anaerobic	Enhanced Biodegradation
Enhanced Biodegradation, Anaerobic In Situ	Enhanced Biodegradation
Enhanced Rhizosphere Biodegradation	Phytoremediation
Enhanced Rhizosphere Biodegradation	Phytoremediation
Enhanced Volatilization	Soil Vapor Extraction
Excavation, Retrieval, and Off-Site Disposal	Excavation, Retrieval, and Off-Site Disposal
Fiber Optic Heat Enhanced SVE	Soil Vapor Extraction, Thermally Enhanced
Filtration	Separation
Flocculation	Precipitation/Coagulation/Flocculation
Fluid/Vapor Extraction	Fluid/Vapor Extraction
Fluidized Bed Incineration	Incineration
Fluidized Bed Furnace	Incineration

Forage Sponge	Adsorption/Absorption
Fracturing	Fracturing
Free Product Recovery	Dual Phase Extraction
Free Product Recovery	Bioslurping
Freeze Crystallization	Separation
Fungal Biodegradation	Fungal Biodegradation
Funnel and Gate	Passive/Reactive Treatment Walls

TOP

Technology/Synonym	Go To
GAC	Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption
Glycolate Dehalogenation	Dehalogenation
Granulated Activated Carbon (GAC)	Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption
Gravity Separation, Soil	Separation
Ground Water Pumping (for containment)	Ground Water Pumping (for containment)
Heap Pile Bioremediation	Biopiles
High Energy Corona	High Energy Destruction
High Energy Destruction	High Energy Destruction
High Temperature Thermal Desorption	Thermal Desorption
Horizontal Wells	Directional Wells
Hot Air Injection	Hot Gas Decontamination
Hot Gas Decontamination	Hot Gas Decontamination
Hot Water Flushing	Hot Water or Steam Flushing/Stripping
Hot Water Flushing/Stripping	Hot Water or Steam Flushing/Stripping
Hot Water Stripping	Hot Water or Steam Flushing/Stripping

Hydraulic Control	Phytoremediation
Hydrodynamic Barriers	Slurry Walls
Hydrofracturing	Hydrofracturing
Hydrous Pyrolysis/Oxidation	Hot Water or Steam Flushing/Stripping

TOP

Technology/Synonym	Go To
In Situ Aeration	Air Sparging
In Situ Chemical Filters	Passive/Reactive Treatment Walls
In Situ Soil Venting	Soil Vapor Extraction
In Situ Vitrification	Solidification/Stabilization
In Situ Volatilization	Soil Vapor Extraction
Incineration	Incineration
Infra-Red Combustion	Incineration
In-Place Bioreaction	Passive/Reactive Treatment Walls
In-Situ Air Sparging	Air Sparging
In-Situ Steam Extraction	Hot Water or Steam Flushing/Stripping
Internal Combustion Engine Oxidation	Oxidation
Intrinsic Bioremediation	Natural Attenuation
Intrinsic Bioremediation	Natural Attenuation
Intrinsic Remediation	Natural Attenuation
Intrinsic Remediation (GW)	Natural Attenuation
In-Well Aeration	In-Well Air Stripping
In-Well Air Stripping	In-Well Air Stripping
Ion Exchange	Ion Exchange
Iron Treatment Walls	Passive/Reactive Treatment Walls

Landfarming, Ex Situ	Landfarming
Landfarming, In Situ	Land Treatment
Landfill Cap	Landfill Cap
Landfill Cover	Landfill Cap
Land Tilling	Land Treatment
Land Treatment	Land Treatment
Lasagna Process	Fracturing
Lignin Adsorption	Adsorption/Absorption
Liquid-Liquid Extraction	Dual Phase Extraction
Liquid Phase Adsorption	Adsorption/Absorption
Liquid Phase Carbon Adsorption	Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption
Low Temperature Thermal Desorption	Thermal Desorption

TOP

Technology/Synonym	Go To
Magnetic Separation, Soil	Separation
Membrane Pervaporation	Separation
Membrane Separation	Membrane Separation
Microfiltration	Separation
Modified Sulfur Cement	Solidification/Stabilization
Molten Salt Destruction	Pyrolysis
Molten Solid Processing	Pyrolysis
Multi-phase Extraction	Dual Phase Extraction
Natural Attenuation, Ground Water	Natural Attenuation
Natural Attenuation, Soil	Natural Attenuation
Natural Recovery	Natural Attenuation

Natural Assimilation	Natural Attenuation
Nitrate Enhanced Biodegradation	Enhanced Biodegradation
Off-Site Disposal	Excavation, Retrieval, and Off-Site Disposal
Open Burn/Open Detonation	Open Burn/Open Detonation
Organic Pump	Phytoremediation
Oxidation	Oxidation
Oxygen Enhanced Biodegradation with Air Sparging	Enhanced Biodegradation
Oxygen Enhanced Biodegradation with Hydrogen Peroxide	Enhanced Biodegradation

TOP

Technology/Synonym	Go To
Passive Treatment Walls	Passive/Reactive Treatment Walls
Passive/Reactive Treatment Walls	Passive/Reactive Treatment Walls
Permeable Reactive Barriers	Passive/Reactive Treatment Walls
Physical Separation, Soil	Separation
Phyto-accumulation	Phytoremediation
Phyto-degradation (GW)	Phytoremediation of Organics
Phytoremediation (GW)	Phytoremediation
Phyto-degradation (soils)	Phytoremediation
Phytoremediation (soils)	Phytoremediation
Phyto-stabilization	Phytoremediation
Phyto-volatilization	Phytoremediation
Plasma Pyrolysis	Pyrolysis
Pneumatic Fracturing	Fracturing
Polyethylene Extrusion Process	Solidification/Stabilization

Pozzolan Process/Portland Cement	Solidification/Stabilization
Precipitation	Precipitation/Coagulation/Flocculation
Precipitation by Oxygen Saturation	Precipitation/Coagulation/Flocculation
Pump and Treat	Ground Water Pumping (for containment)
Pyrolysis	Pyrolysis
Radio Frequency/Electromagnetic Heating	Soil Vapor Extraction, Thermally Enhanced
Radioactive Waste Solidification (Grouting/Other)	Solidification/Stabilization
RBC	Bioreactors
RCRA Subtitle C Landfill Cap	Landfill Cap
RCRA Subtitle D Landfill Cap	Landfill Cap
Reactive Treatment Walls	Passive/Reactive Treatment Walls
Reverse Osmosis	Separation
Rotary Kiln Incineration	Incineration
Rotary Kiln Pyrolysis	Pyrolysis
Rotating Biological Contactor	Bioreactors
Rotating Biological Reactor	Bioreactors

TOP

Technology/Synonym	Go To
Separation, Ground Water	Separation
Separation, Soil	Separation
Sieving and Physical Separation, Soil	Separation
Sludge Stabilization (Aggregate /Rock/Slag)	Solidification/Stabilization
Slurry Biodegradation	Slurry Phase Biological Treatment
Slurry Phase Biological Treatment	Slurry Phase Biological Treatment

Slurry Trenches	Slurry Walls
Slurry Walls	Slurry Walls
Soil Flushing	Soil Flushing
Soil Vapor Extraction, Ex Situ	Soil Vapor Extraction
Soil Vapor Extraction, Thermally Enhanced	Soil Vapor Extraction, Thermally Enhanced
Soil Washing	Soil Washing
Solid Phase Biodegradation	Landfarming
Solid Phase Treatment	Land Treatment
Solid Phase Treatment	Composting
Solidification/Stabilization, Ex Situ Soil	Solidification/Stabilization
Solidification/Stabilization, In Situ Soil	Solidification/Stabilization
Soluble Phosphates	Solidification/Stabilization
Solvent Extraction	Chemical Extraction
Sorptive Clays	Adsorption/Absorption
Sprinkler Irrigation	Sprinkler Irrigation
Stabilization, Ex Situ	Solidification/Stabilization
Static-Pile Composting	Biopiles
Steam Flushing	Hot Water or Steam Flushing/Stripping
Steam Flushing/Stripping	Hot Water or Steam Flushing/Stripping
Steam Stripping	Hot Water or Steam Flushing/Stripping
Subsurface Injection	Deep Well Injection
Supercritical Fluid Enhanced SVE	Soil Vapor Extraction
Surface Covers	Landfill Cap
Surfactant Enhanced Recovery Pump and Treat	Ground Water Pumping (for containment)
Synthetic Resin Adsorption/Absorption	Adsorption/Absorption

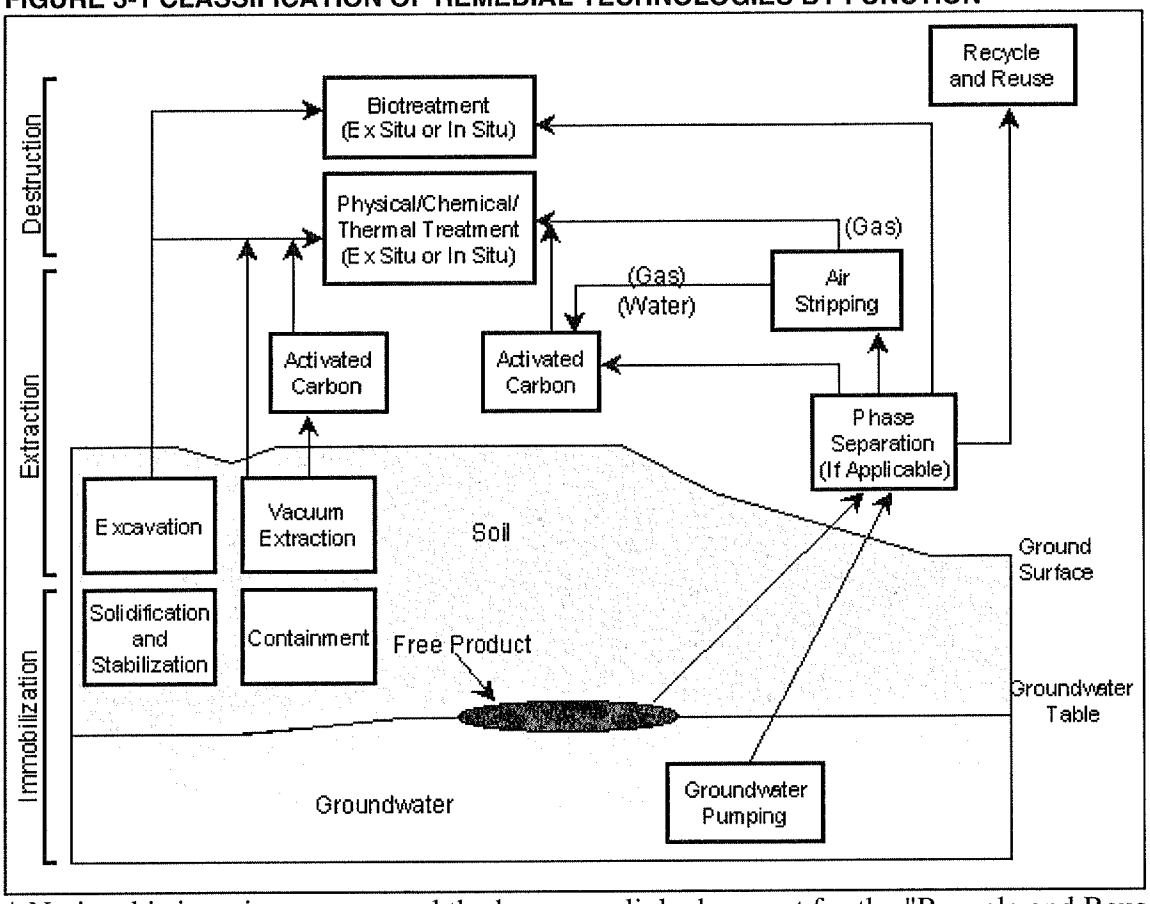
TOP

Technology/Synonym	Go To
Thermal Desorption	Thermal Desorption
Thermal Oxidation	Oxidation
Treatment Walls	Passive/Reactive Treatment Walls
Trickling Filter	Sprinkler Irrigation
Tunable Hybrid Plasma Reactor	High Energy Destruction
Two Phase Extraction	Fluid/Vapor Extraction
Two-Phase Pumping	Ground Water Pumping (for containment)
Ultrafiltration	Separation
Ultraviolet Oxidation, Air	Oxidation
Ultraviolet Oxidation, Ground Water	Ultraviolet Oxidation
Ultraviolet Photolysis	Ultraviolet Oxidation
Underground Injection	Deep Well Injection
UV Photolysis	Ultraviolet Oxidation
UV/Oxidation, Air	Oxidation
UV/Ox, Ground Water	Ultraviolet Oxidation
Vacuum Enhanced Extraction	Dual Phase Extraction
Vacuum Vapor Extraction	In-Well Air Stripping
Vacuum Vaporizer Well	In-Well Air Stripping
Vapor-Phase Carbon Adsorption	Vapor-Phase Carbon Adsorption
Vegetation-Enhanced Bioremediation	Phytoremediation
Vegetation-Enhanced Bioremediation	Phytoremediation
Vegetative Cover	Landfill Cap Enhancements
Vertical Cutoff Wall	Slurry Walls
Vitrification, In Situ	Solidification/Stabilization

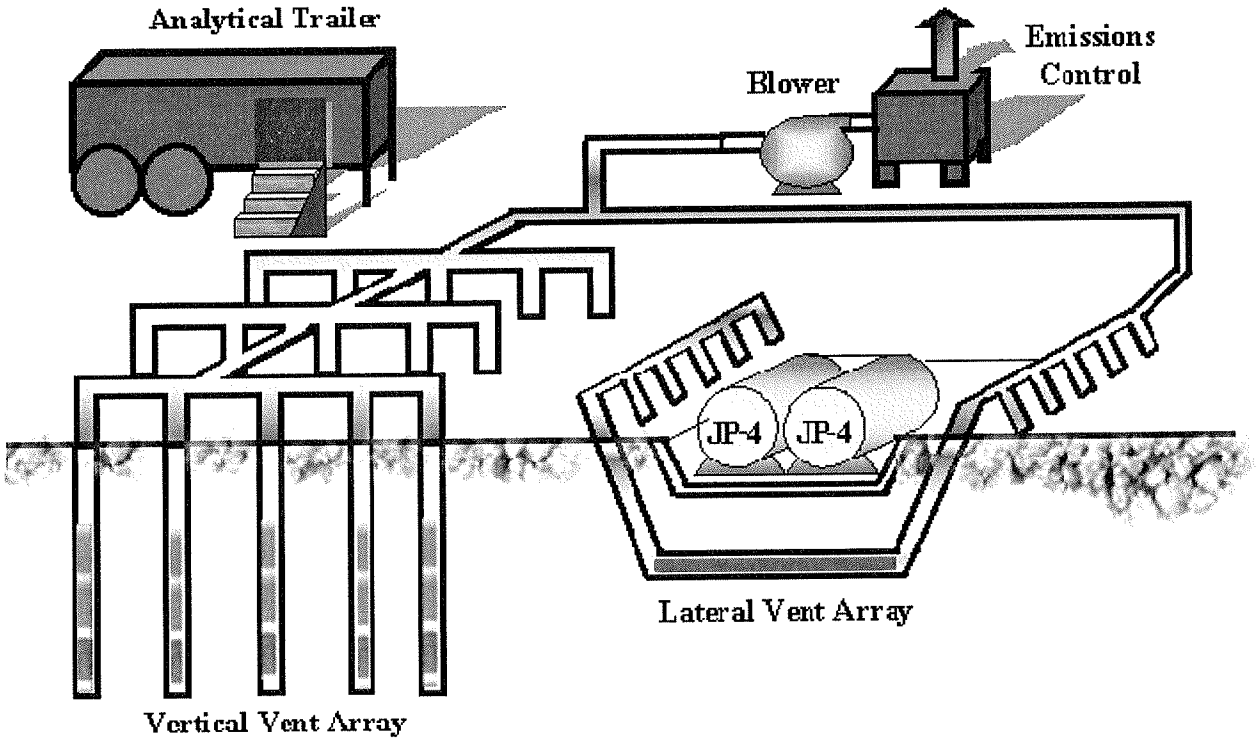
Vitrification/Molten Glass Stabilization	Solidification/Stabilization
VOC Recovery and Recycle	Vapor-Phase Carbon Adsorption
Water Harvesting	Landfill Cap Enhancements
White Rot Fungus	Fungal Biodegradation

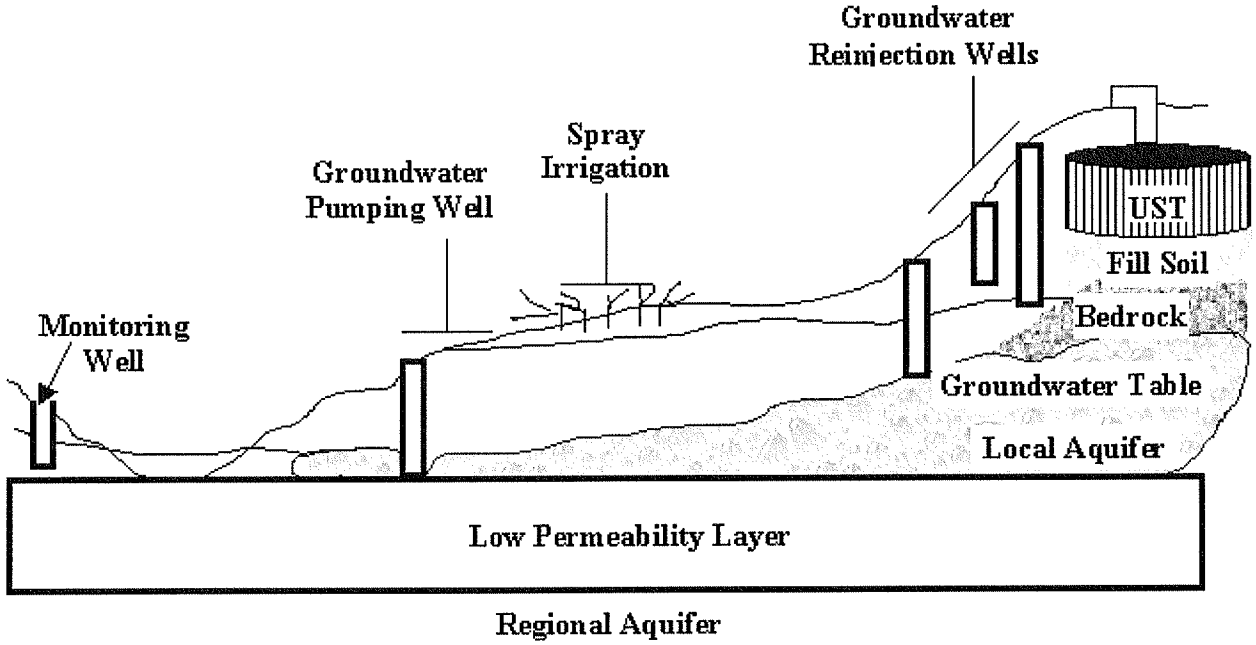
TOP

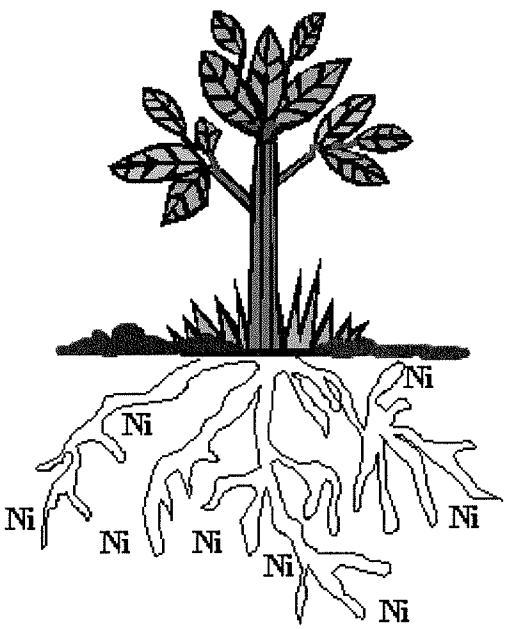
FIGURE 3-1 CLASSIFICATION OF REMEDIAL TECHNOLOGIES BY FUNCTION*

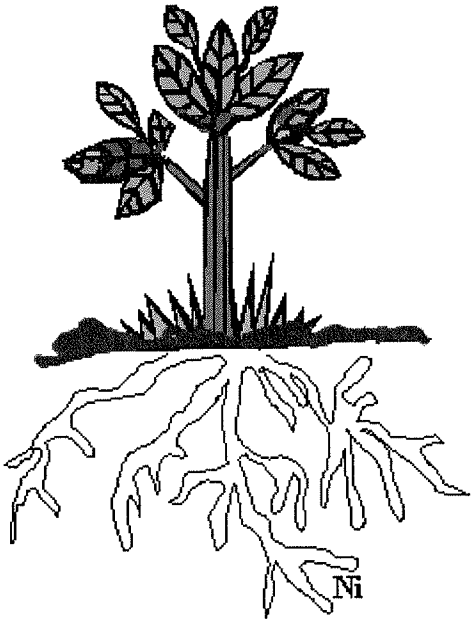


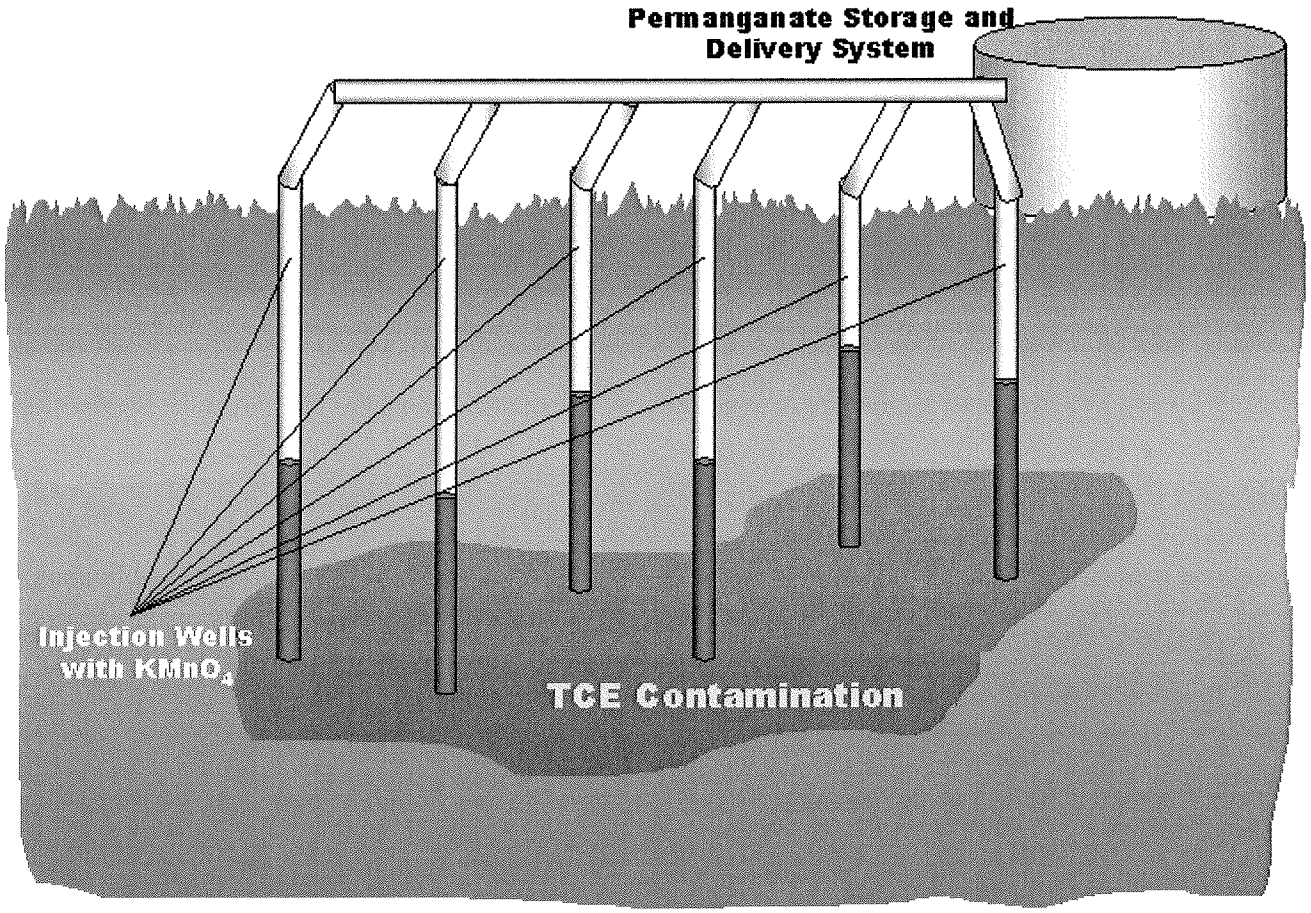
* Notice this is an image map and the boxes are linked, except for the "Recycle and Reuse" box.

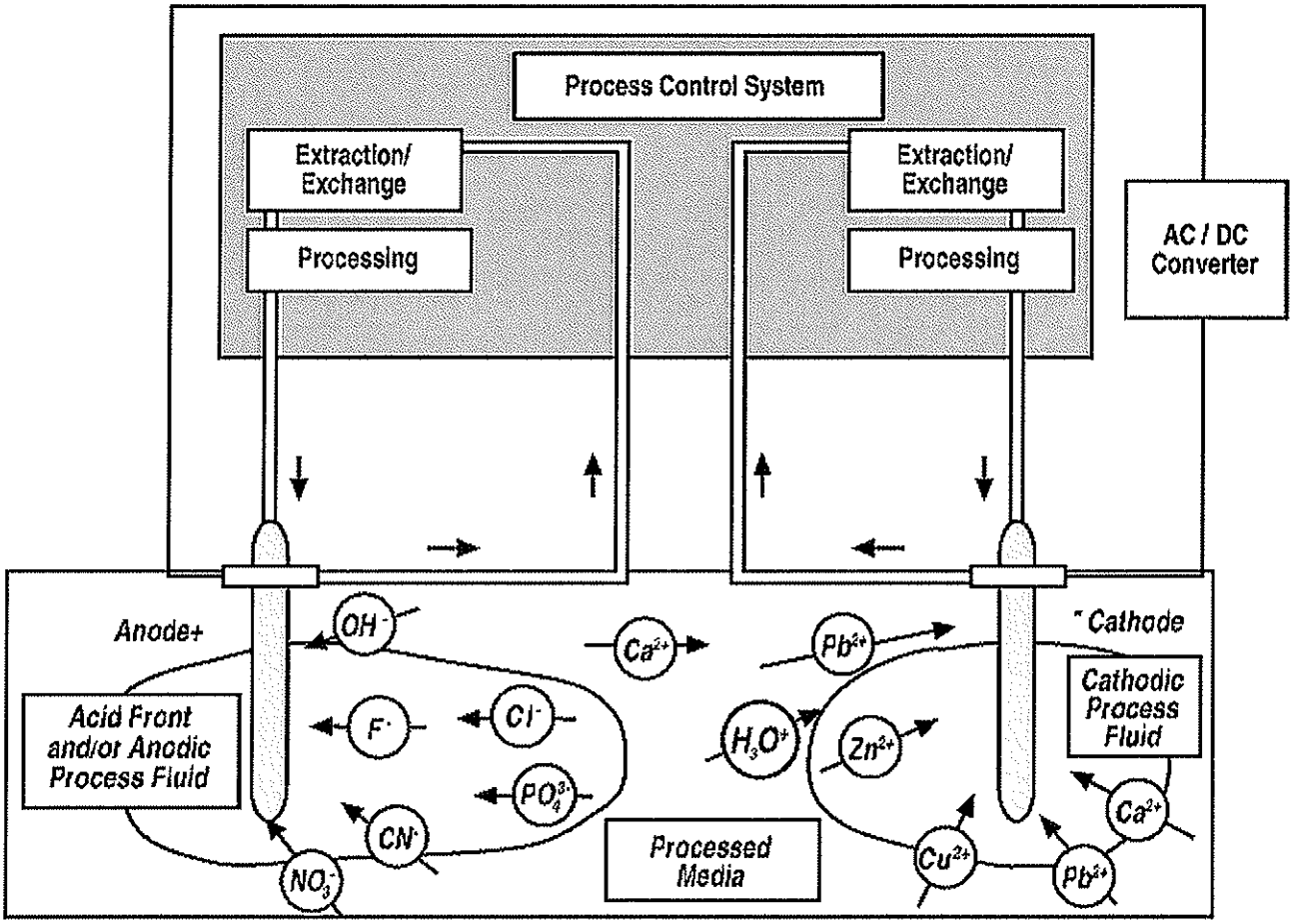

Analytical Trailer
Blower
Emissions Control
JP-4
JP-4
Lateral Vent Array
Vertical Vent Array

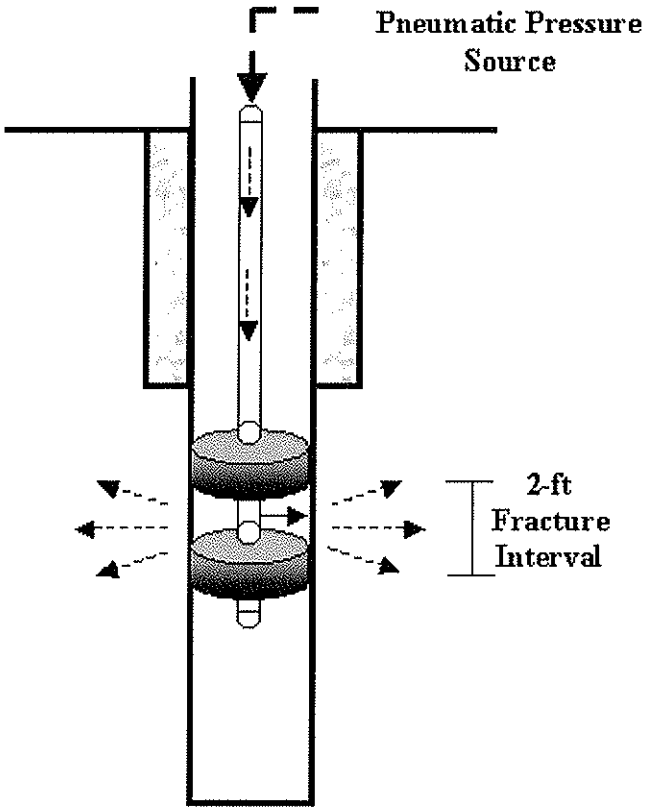

Groundwater
Reinjection Wells
Spray
Irrigation
Groundwater
Pumping Well
UST
Fill Soil
Monitoring
Well
Bedrock
Groundwater Table
Local Aquifer
Low Permeability Layer
Regional Aquifer

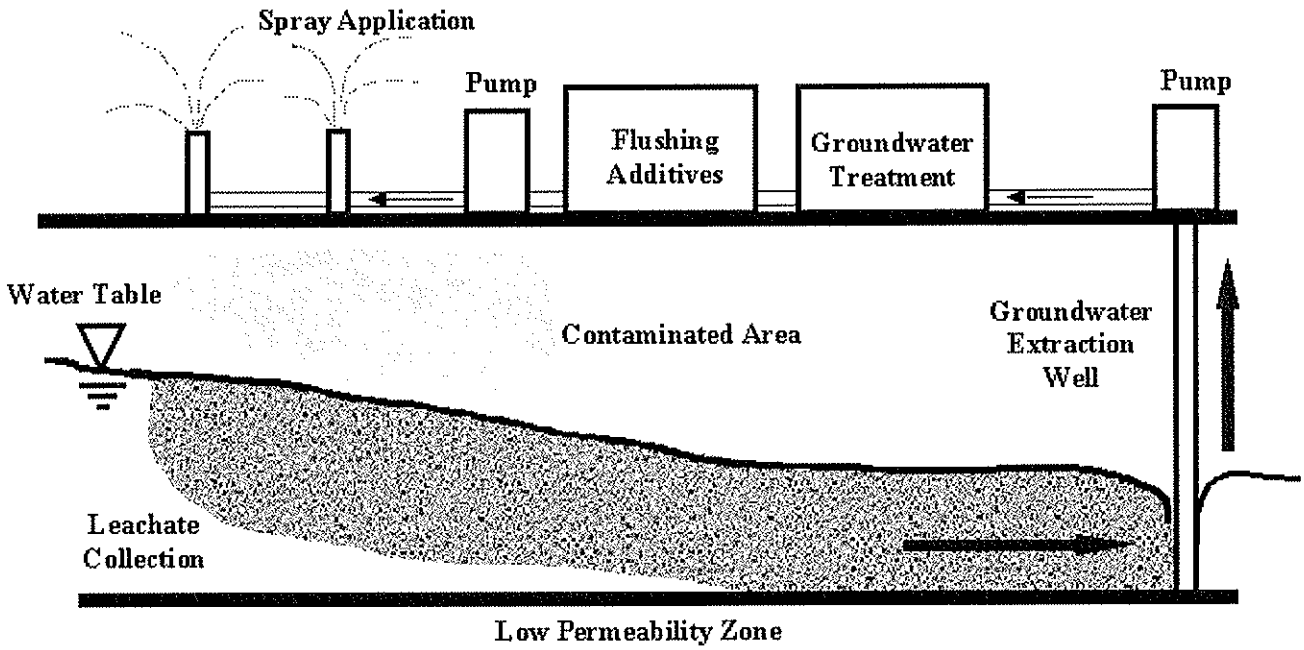

Ni
Ni
Ni
Ni
Ni
Ni
Ni
Ni

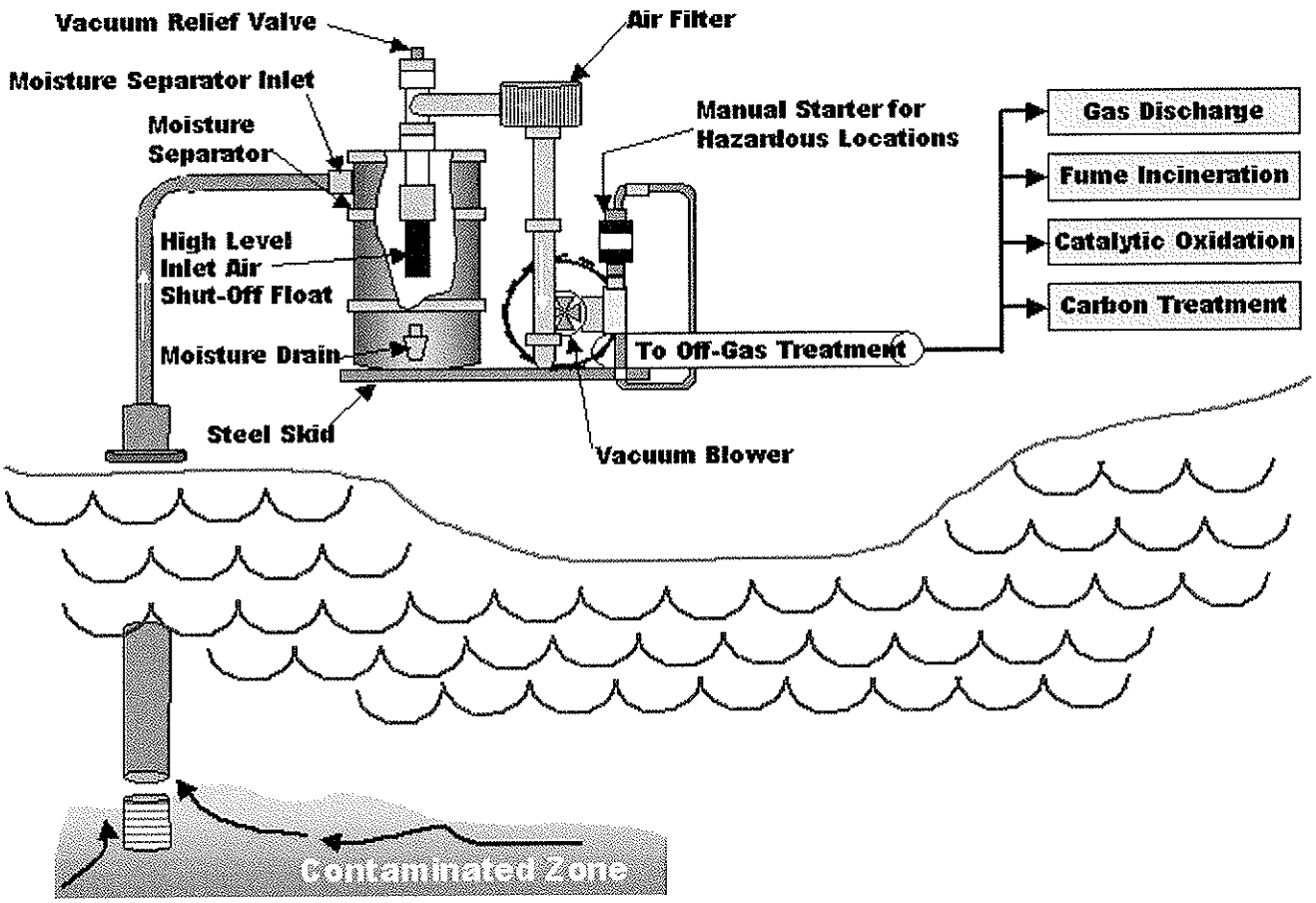

Ni

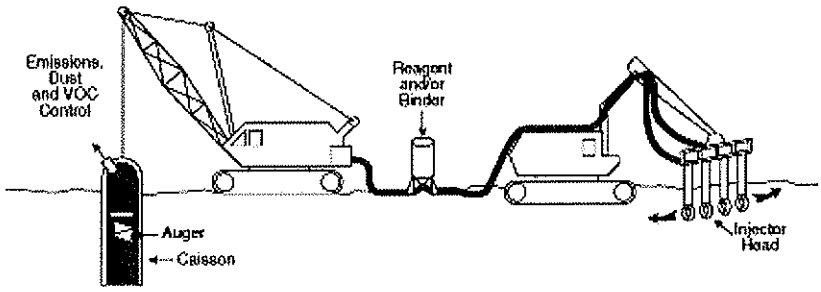

Permanganate Storage and Delivery System
Injection Wells with $KMnO_4$
TCE Contamination


Process Control System
Extraction/ Exchange
Processing
Extraction/ Exchange
Processing
AC / DC Converter
Anode+
Cathode
Acid Front and/or Anodic Process Fluid
Cathodic Process Fluid
Processed Media
OH-
Ca2+
Pb2+
F-
Cl-
H3O+
Zn2+
PO43-
CN-
NO3-
Cu2+
Pb2+
Ca2+


Pneumatic Pressure
Source
2-ft
Fracture
Interval


Spray Application
Pump
Flushing Additives
Groundwater Treatment
Pump
Water Table
Contaminated Area
Groundwater Extraction Well
Leachate Collection
Low Permeability Zone


Vacuum Relief Valve
Air Filter
Moisture Separator Inlet
Moisture Separator
Manual Starter for Hazardous Locations
Gas Discharge
Fume Incineration
Catalytic Oxidation
Carbon Treatment
High Level Inlet Air Shut-Off Float
Moisture Drain
To Off-Gas Treatment
Steel Skid
Vacuum Blower
Contaminated Zone



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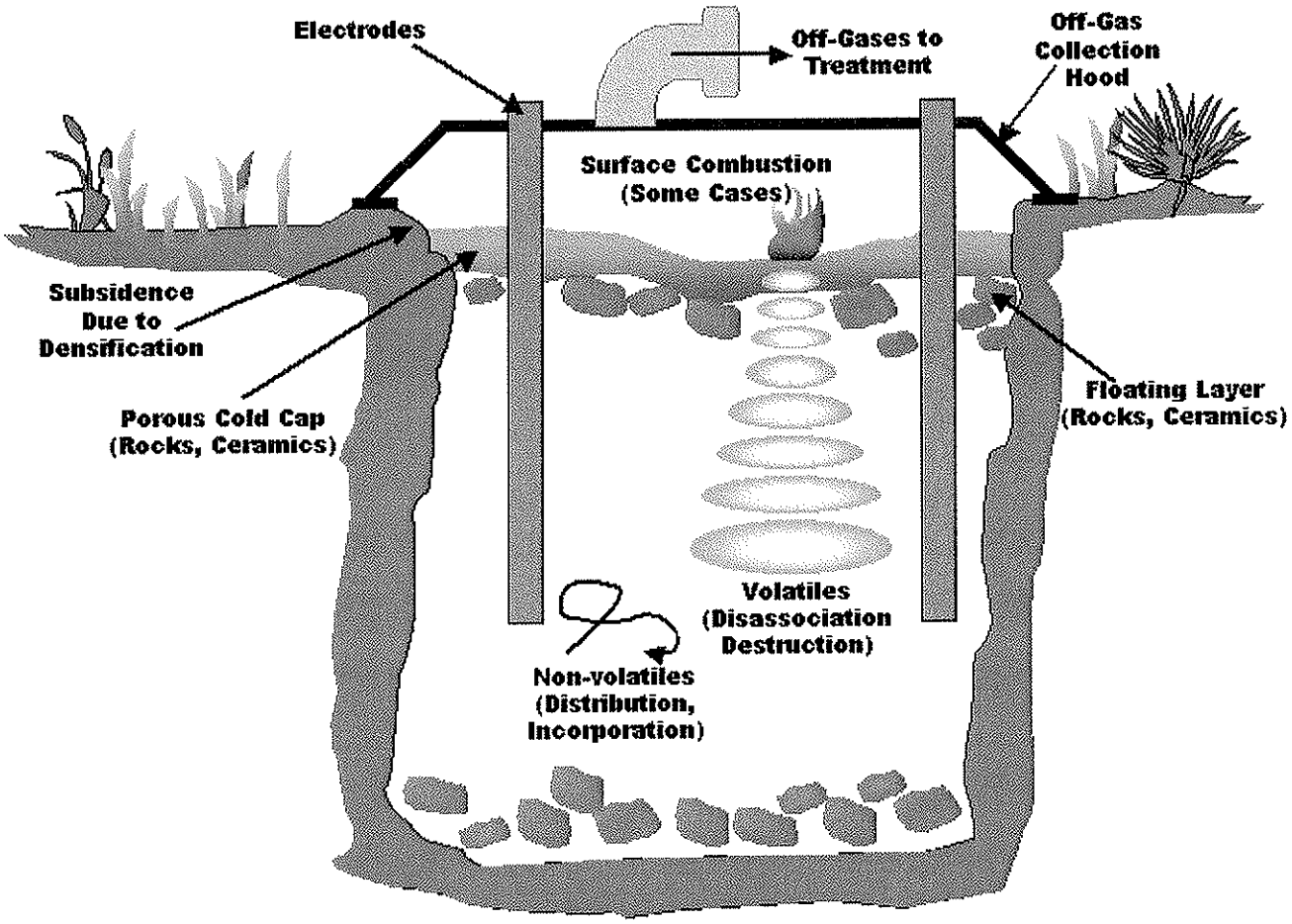
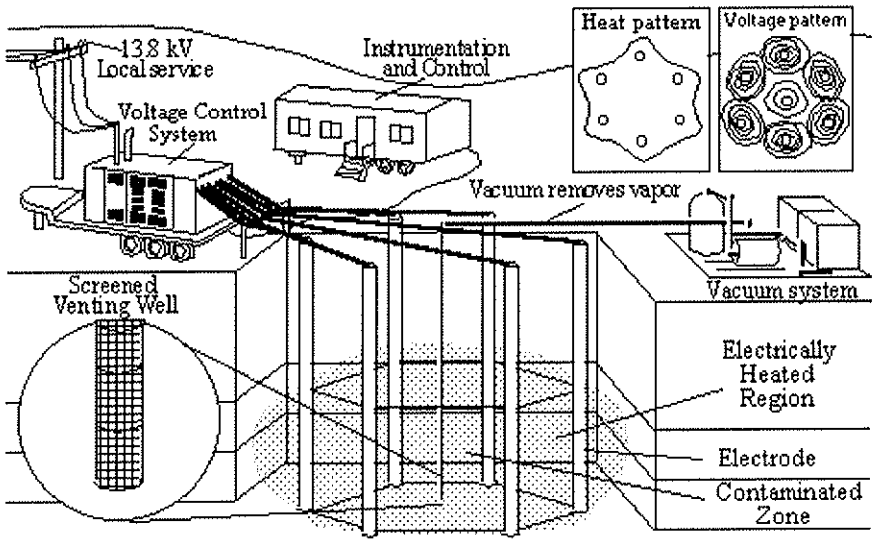

Electrodes
Off-Gases to Treatment
Off-Gas Collection Hood
Surface Combustion (Some Cases)
Subsidence Due to Densification
Porous Cold Cap (Rocks, Ceramics)
Floating Layer (Rocks, Ceramics)
Volatiles (Disassociation Destruction)
Non-volatiles (Distribution, Incorporation)


Heat pattern
Voltage pattern
138 kV
Local service
Instrumentation
and Control
Voltage Control
System
Vacuum removes vapor
Vacuum system
Screened
Venting Well
Electrically
Heated
Region
Electrode
Contaminated
Zone

North Wind, Inc.

CONTRACT RELEASE NO. 3

To: File, Margie Stockton, Peter Maggiore, Ron Ward, Laura Day, and Sylvia Medina
From: Trudy E. Carrillo
Date: January 28, 2009

Executive Summary:	**Modification No. 2 increases funding and adds a new labor category**
Client:	**Los Alamos National Security, LLC (LANS)**
Project No.:	**5602.001**
Task Name:	**LANL AQ Rad NESHAP**
Division/Unit No.:	05/56
Project Manager:	Margie Stockton
Contract Type:	Time & Materials
Contract No.:	**593190-002-08**
Modification No.:	**2**
Government or Commercial:	**DOE.LANL**
Task Revenue Requirements:	**No**
Task A/R Requirements:	**No**
Include ODC's in Revenue Amount:	**Yes**
Apply G&A to ODC's:	**11.16%**
Award Type:	Sole Source/ SB Award/ 8a Award
New Mexico Gross Receipts Tax:	**7.0625% (on subs only; NW direct labor charges under non-tax exemption)**
O/H Onsite (NW location)	**$89.80**
O/H Offsite (Customer location)	**$53.38**
Award Amount:	$218,266 $158,411 – Mod No. 1 **$ 54,470 – Mod No. 2** **$431,147**
Funded Amount:	$218,266 $158,411 – Mod No. 1 **$ 54,470 - Mod No. 2** **$431,147**

Contracting Officer:	Diane McHugh (505) 606-1795
Technical Representative:	Steve Story (505) 665-2169
Start Date:	**12/01/07**
End Date:	**11/30/09**

Accounting – Please submit monthly billings with the following signed certification:

> "The undersigned certifies that the information set forth herein is true and correct and may be used as a basis for payment by LANS for the work performed."
>
> Invoices must also have Client Cost Code (PM will inform Accounting)

All invoices shall be addressed to:

Los Alamos National Security, LLC
Los Alamos National Laboratory
Accounting Department, MS P240
P.O. Box 1663
Los Alamos, NM 87545-1663

And emailed to: invoices@lanl.gov

Modification Number 2

The subcontract between Los Alamos National Security, LLC (CONTRACTOR) and North Wind, Inc. (SUBCONTRACTOR) is modified as described herein. Except as modified, all other terms and conditions remain unchanged and in full force and effect. This modification is effective on the date of signature by the last party to sign.

MODIFICATION

Modification #2 is issued increase the ceiling price, update the labor allocation to incorporate additional labor hours, increase Hazair's labor rate inclusive of a 3% escalation rate and update the STR as follows:

#1) Paragraph 6, Ceiling Price is deleted in its entirety and replaced with the following:

"The Ceiling Price for all work called for under this Task Order is $431,147.00.

(a) The maximum amount (Not-to-Exceed) that CONTRACTOR shall be liable for reimbursement of Direct Labor charges is *$385,846.00.*

(b) The maximum amount (Not-to-Exceed) that CONTRACTOR shall be liable for reimbursement of Other Direct charges is *$42,716.00.*

(c) The maximum amount (Not-to-Exceed) that CONTRACTOR shall be liable for reimbursement of Travel charges is *$2,585.00."*

#2) Paragraph #8, is deleted in its entirety and replaced with the following:

"SUBCONTRACTOR'S labor categories, level of effort for each category and the fixed hourly rates upon which the Not-to-Exceed amount for reimbursement of Direct Labor charges is based are listed below. Reimbursement for Direct Labor shall be at the fixed hourly rates listed below for the actual effort performed by each category. The Subcontractor may vary the hours to complete the work; however, the reimbursement for the entire work shall not exceed the total authorized funds. The Subcontractor shall notify and obtain the LANS STR concurrence regarding any deviation of the level of effort.

Labor Category	Level of Effort	Hourly Rate
Technical Staff Consultant – Home Office- Yr 1	4	$166.50
Technical Staff Consultant – Home Office- Yr 2	4	$172.74
Manager II – Home Office Yr 1	8	$130.50
Program Manager- Home Office Yr 2	16	$146.17
Prin. Reg. Analyst Client Site Yr 1	1960	$77.80
Prin. Reg. Analyst Client Site Yr 2	1960	$80.72

Sr, Scientific Specialist, Home Office	TBD	$80.96
Associate Scientist, Client Site Yr1	40	$30.29
Env Scientist- Client Site Yr 2	**1460**	**$41.90**
Sr. Project Controls Specialist, Home Office Yr1	20	$80.34
Prin. Project Controls Specialist, Home Office Yr 2	32	$99.51
Prin Admin Assistant, Home Office Yr 1	48	$42.08
Technical Admin Spec, Home Office Yr 2	24	$50.44
Total Estimated Hours	**5736"**	
Hazair (Sub-Tier) Pat Nelson		**$111.24**

#3) Paragraph #9 is deleted in its entirety and replaced with the following:

"CONTRACTOR'S Subcontract Technical Representative for this task order is:

Douglas Stavert
Los Alamos National Security, LLC
Los Alamos National Laboratory
P.O. Box 1663, Mail Stop J978
Phone: (505) 665-0235
Fax: (505) 665-4747
Email: stavert@lanl.gov"

End of Modification #2

The undersigned personally asserts that he or she is authorized to execute this release on behalf of the Subcontractor.

For the Subcontractor:

By: _____

Name: Brad D. Nelson

Title: Sr. Contract Administrator

Date: 1/28/09

For LANS:

By: _____

Name: Diane McHugh

Title: Team Leader

Date: 1/27/2009

North Wind, Inc.

CONTRACT RELEASE NO. 1

To: File, Julien Boyance, Ron Ward, Laura Day, and Sylvia Medina
From: Trudy Carrillo
Date: January 27, 2009

Executive Summary: **New Contract**

Client **Los Alamos National Security (LANS)**

Project No. **10005**
Project Name: **LANL Deep Drilling MTOA**

Task No:	**Type:**	**Task Name:**	**Budget:**
10005.001	**FP**	**Drilling ES&H Plan**	**$27,604**

Division/Unit No.:	05/56
Project Manager:	Julien Boyance
Contract Type:	Determined by Task
Contract No.:	
Other Contract No.	
Org No.	**1.01.05**
Modification No.:	**0**
Government or Commercial:	DOE.LANL
Task Revenue Requirements:	**Yes**
Task A/R Requirements:	**Yes**
Include ODC's in Revenue Amount:	**Yes**
Apply G&A to ODCs:	11.70%
New Mexico Gross Receipts Tax:	**7.0625%**
Firm Fixed Price Fee:	**8%**
Total Award Amount:	**$14,000,000**
Funded Amount:	**Determined at Task Level**
Contracting Officer:	Terrance Forrester (505) 665-1739 *Forrester_terrance@lanl.gov*
Award Type:	Competed
Start Date:	**01/08/09**
End Date:	

Accounting – Please submit monthly billings with the following signed certification:

> "The undersigned certifies that the information set forth herein is true and correct and may be used as a basis for payment by LANS for the work performed."

All invoices shall be addressed to:

Los Alamos National Security, LLC
Los Alamos National Laboratory
Accounting Department, MS P240
P.O. Box 1640
Los Alamos, NM 87545

MAINTAIN PROJECT MASTER

Project Number *(5 digit, assigned by Contracts Dept Level 1)* 10005.000
Project Name: *(up to 25 characters)* LANL Deep Drilling MTOA
Project Type: (CPFF, FP, T&M) ~~Choose an item.~~ TBD @ task order
Customer / Client Name: LANS
Assigned Project Manager: [redacted] Julien Bryance?
Prime Contract No. *(with the government, whether NWI is prime or sub)*
Subcontractor No . *(NWI's signed contract # with the customer, when NWI is sub to prime)*
Purchase Order No.
Owning Organization: ~~Choose an item.~~ 1.01.05 (LANL)
Project Work Force Required ☐ TBD @ task order
Use Top Level Work Force ☒ No – task order level

LEVEL SET UP OR WBS

Description: *(required to the task level only)*

LANL Deep Drilling MTOA

Project (5)	Task (3)	WP (2)	Activity (2)
XXXXX	XXX	XX	XX
10005	000		

GOVERNMENT INFORMATION

Funding Source
Contract Officer ? Terrence Forrester
~~Admin~~ Officer Tech
~~Procurement Officer~~ [redacted]
NWI Contract Representative Brad Nelson
~~Contractor Representative Title~~ ✓ Contract

Wage Determination *(use PLC for Wage Determination)* ☐
Admin Officer Phone #
Admin Officer Email
Contract Representative Phone # 505-
Statement of Work

USER DEFINED INFORMATION

Business	Choose an item. ?
Women Owned	Yes (•) No
Disadvantaged	Yes (X) No
8(a)	( ) Yes ( ) No
Customer Type (choices)	Choose an item. ?
Award Type (Competed, Open Comp, SS)	Choose an item. Competed/Open Competition
QA Designation	( ) Yes ( ) No

MODIFICATIONS (and initial signed value)

ID *(Mod Number)*	0
Description *(Description of Mod)*	Initial Award
Effective Date *(Effective Date the Mod was issued)*	Click here to enter a date. 1/8/09
Period of Performance	Start Date: ~~Click here~~ End Date Click here 1/8/09 - ?
Value	~~$0~~ $14,000,000
Fee%	
Funding	$0
Fee%	

Award Fee Information

Unit Information

BASIC REVENUE

Revenue Formula	Choose an item. ?

PROJECT LOCATION

Address

PROJECT BILLING INFORMATION

Level of Billing (top, task, activity)	TBD @ task order
Formula (15 choices)	~~Choose an item.~~ ?
Fee % (If CPFF or FP)	TBD @ task order / 8%
Retainage (Basis for Calculation)	~~Choose an item.~~ ?
Billing Cycle *(look up available)*	?
Income State (tax purposes)	NMGRT on lower-tier subs

EMPLOYEE LABOR CATEGORIES (T&M)

Labor Category Description	Employee	Rate	Start Date	End Date

SUBCONTRACTOR/CONSULT LABOR CATEGORIES (T&Ms)

Labor Category Description	Vendor	Rate	Start Date	End Date

CEILINGS

MAINTAIN PROJECT MASTER

Project Number *(5 digit, assigned by Contracts Dept Level 1)*	10005.001
Project Name: *(up to 25 characters)*	Drilling Task 1 - PIPs
Project Type: (CPFF, FP, T&M)	~~Choose an item.~~ FFP
Customer / Client Name:	LANS
Assigned Project Manager:	Heather Smith
Prime Contract No. *(with the government, whether NWI is prime or sub)*	?
Subcontractor No . *(NWI's signed contract # with the customer, when NWI is sub to prime)*	66270-001-#08
Purchase Order No.	—
Owning Organization:	~~Choose an item.~~ 1.01.05 (LANL)
Project Work Force Required	☐ No
Use Top Level Work Force	☐

LEVEL SET UP OR WBS

Description: *(required to the task level only)*

Project Initiation Plans

Project (5)	Task (3)	WP (2)	Activity (2)
XXXXX	XXX	XX	XX
10005	001		

GOVERNMENT INFORMATION

Funding Source	
Contract Officer	Terrence Forrester
Admin Officer	
Procurement Officer	
NWI Contract Representative	Brad Nelson
Contractor Representative Title	
Wage Determination *(use PLC for Wage Determination)*	☐
Admin Officer Phone #	
Admin Officer Email	
Contract Representative Phone #	
Statement of Work	

USER DEFINED INFORMATION

Business	~~Choose an item.~~ ?
Women Owned	○ Yes ◉ No
Disadvantaged	○ Yes ○ No
8(a)	○ Yes ○ No
Customer Type (choices)	Choose an item.
Award Type (Competed, Open Comp, SS)	~~Choose an item.~~ Competed / Open Competition
QA Designation	○ Yes ○ No

MODIFICATIONS (and initial signed value)

ID *(Mod Number)*	Ø
Description *(Description of Mod)*	Initial Award
Effective Date *(Effective Date the Mod was issued)*	~~Click here to enter a date.~~ 1/8/09 – ?
Period of Performance	Start Date: ~~Click here~~ 1/9/09 End Date ~~Click here~~
Value	27,604 ??
Fee%	
Funding	27,604 ??
Fee%	

Award Fee Information

Unit Information

BASIC REVENUE

Revenue Formula — Choose an item.

PROJECT LOCATION

Address

PROJECT BILLING INFORMATION

Level of Billing (top, task, activity)	Task
Formula (15 choices)	Choose an item.
Fee % (if CPFF or FP)	8 %
Retainage (Basis for Calculation)	Choose an item.
Billing Cycle *(look up available)*	
Income State (tax purposes)	

EMPLOYEE LABOR CATEGORIES (T&M)

Labor Category Description	Employee	Rate	Start Date	End Date

SUBCONTRACTOR/CONSULT LABOR CATEGORIES (T&Ms)

Labor Category Description	Vendor	Rate	Start Date	End Date

CEILINGS

North Wind

CONTRACT DATA ENTRY FORM

Required Information

Project Number *(assigned by Contracts Dept)*: 10005.001	**NOTE:** *Do Not Activate in System until Page Two Completed by Line or Project Manager*
Region/ Product Line *(Profit & Loss Center assigned by CFO)*: 005 Organizational Breakdown (OBS Number) _____	Customer/Client Name: Los Alamos National Laboratory
Contract Type: ☐ Time & Materials (T&M) ☒ Firm Fixed Price (FFP) ☐ Cost Plus (CP)	Prime Govt. Contract No. *(whether NWI is prime or sub)*:
Subcontracting No. *(when NWI is sub to prime)*:	Quality Level (Q or N) _____
Contracting Officer Information: Name: Terrence Forrester Address: P.O. Box 1663, MS D442 Los Alamos, NM 87544 Phone: 505-665-1739 E-mail: Forrester_terrence@lanl.gov	Tech Officer Information: Name: TBD Address: _____ _____ Phone: _____ E-mail _____
Customer Type: ☒ Government ☐ Commercial	If Government: ☐ DOD ☒ DOE ☐ DOI ☐ BLM ☐ Nat'l Park Forest Service ☐ Other _____
Billing Address: Los Alamos National Laboratory **OR** Contract _____ Page # _____ _____	Award Amount: $27,604 Funded/Obligated Amount (If applicable): $27,604
Contract Start/End Dates: Starts: 1/8/09 Ends: _____	If Contract is Firm-Fixed-Price, enter Fee %: 8 %
If Contract is T&M, do terms allow ODCs? ☐ Yes ☐ No	If Contract is T&M, do terms allow G&A on ODCs? ☐ Yes _____ % ☒ No
If Contract is T&M, do terms allow fee on ODCs? ☐ Yes _____% ☐ No	Subcontractor G&A (*if staff aug*) or M&S (*if sub has independent deliverables*) & profit: G&A _____ % M&S: 4 %
North Wind Inc. Profit on Subcontractor Rates: 6 %	If Contract is Cost Plus: OH___% G&A___% M&S___% Fee___%
Apply State Taxes/Fees (*WA-B&O, NM-Gross Receipts, etc)*? Rates:7.0625 %	Government Labor Rates apply? ☐ No ☐ Davis/Bacon ☐ SCA
Award Profile: ☒ Competed ☐ Sole Source ☐ SB Award ☐ 8(a) Award	O/H Onsite (North Wind Inc. Location): 96.01 O/H Offsite (Customer Location): 52.79

North Wind

CONTRACT DATA ENTRY FORM

Contract Administrator: _____ _____
Signature Date

North Wind

CONTRACT DATA ENTRY FORM

Information to be filled out by the Line Manager or Project Manager

Project Number *(from Page 1 of 2)*: ~~5510~~	**Contract/Project will not be activated in Business System until this page completed.**
Assigned Project Manager: Doug Jorgensen	Task Name (if single task): Drilling ES&H Plan
IF multiple tasks, THEN list or attach task names and funding amounts: Task 1: _____ $ _____ Task 2: _____ $ _____ Task 3: _____ $ _____ Task 4: _____ $ _____ Task 5: _____ $ _____ Task 6 _____ $ _____	Revenue and Invoice Management *(check one)*: ☐ Project Level *(multiple tasks managed at project level-all tasks will roll up to one invoice amount)* ☒ Task Level *(managed/invoiced at task level)* ☐ Other *(invoiced at project level, managed at task level)* **If have questions, please call Business Systems Administrator at 208-557-7881**
Project budget to be entered in Business System? Yes ☐ No ☐	IF Yes, list or attach BUDGET: Unburdened NWI Labor $ _____ Unburdened Travel $ _____ Unburdened ODCs $ _____ Unburdened Subcontractors $ _____ Overhead applied to labor _____ % Materials & Subs (M&S) OH _____ % (if applicable) General & Admin (G&A) _____ % **TOTAL** $ _____

If **Contract** is T&M, then list or attach NWI named or assigned personnel and billing rates.

Name	Billing Rate

If **Subcontractor(s)** perform under this Contract on T&M basis, then list or attach labor rate(s) payable to Subcontractor(s):

Name or Labor Category	Labor Billing Rate
Layne Christensen	

Line or Project Manager: _____ _____

*Signature Date

***By signing the Contract Data Entry Form for award amounts up to $25,000, you are signing your concurrence with all technical and pricing information or requirements located in the contract, task order, or modification.**

North Wind, Inc.

CONTRACT RELEASE NO. 8

To: File, Pete Maggiore, Laura Day, and Sylvia Medina
From: Trudy E. Carrillo
Date: January 14, 2009

Executive Summary: **Modification No. 8 adds task and increases funding**

Client: **University of California (LANL)**

Project No.	**Task Name**
2451.000	Technical Services for TA-21
2451.001	Technical Review
2451.002	Strategy Development
2451.003	Strategy Implementation
2451.004	Mapping
2451.101	Project Plan Development
2451.102	Development of White Papers
2451.103	Lessons Learned/Alternative Approaches
2451.201	MDA H Public Comment
2451.301	MDA A Risk Assessment
2451.401	SVE NOD

Division/Unit No.:	05/56
Project Manager:	Pete Maggiore
Contract Type:	Time & Materials
Subcontract No.:	**35921-001-06 F3**
Modification No.:	**7**
Government or Commercial:	Government - DOE
Task Revenue Requirements:	**No**
Task A/R Requirements:	**No**
Include ODC's in Revenue Amount:	**Yes**
Apply G&A to ODC's:	**12.27%**
Apply Fee to ODC's:	**8.00%**
New Mexico Gross Receipts Tax:	**6.5625%**

Contract Cost:

$ 97,824.00 – Original
$ 47,880.00 – Modification No. 3
$ 40,000.00 – Modification No. 5
$ 50,000.00 – Modification No. 7
$ 40,000.00 – Modification No. 8 (Task 401)
$275,704.00 – TOTAL

Contracting Officer:	Frank Targhetta (505) 665-2253
Technical Contact:	Mark Thacker (505) 665-5342
Start Date:	**3/8/06**
End Date:	**9/30/09**

Accounting – See invoice instructions on pages 4-6 of the contract. Each invoice submitted for payment shall bear the following certification signed by an official of the subcontractor having authority to make such certification:

"The undersigned certifies that the information set forth herein is true and correct and may be used as a basis for payment by the University for effort performed."

Send monthly invoices to the following:

University of California
Los Alamos National Laboratory
Accounting Department, MS P240
P.O. Box 1663
Los Alamos, NM 87545

Los Alamos National Security, LLC
(LANS)

Subcontract Number 35921- 001-06
Modification Number 8

The above referenced subcontract between the Los Alamos National Security, LLC (LANS) and North Wind, Inc., (Subcontractor) is modified as described herein. Except as modified, all other terms and conditions remain unchanged and in full force and effect. This modification is effective on the date of signature by the last party to sign.

Modification: Reference Section F herein

Section F – Special Provisions, Paragraph 1.a. (1) Direct labor Charges. Change as reads: $203,280.00 to read $243,280.00, an increase of $40,000.00

Reference Paragraph 9 Allotment of Funds. Change as reads: $235,704.00; to read $275,704.00, an increase of $40,000.00.

End of Modification

The Subcontractor (X) is ( ) is not required to sign this modification.

For The Subcontractor:	For Los Alamos National Security, LLC (LANS):
By: [signature]	By: _____
Name: Brad D. Nelson	Name: _____
Title: Sr. Contract Administrator	Title: _____
Date: 1/13/09	Date: _____

Trudy Carrillo

From: Laura L. Day
Sent: Wednesday, January 14, 2009 10:40 AM
To: Trudy Carrillo
Cc: Brad Nelson
Subject: FW: Attached Image
Attachments: 1145_001.pdf

Hi Trudy!

Attached is a 40K mod to 2451 that came in yesterday. We will need to invoice these costs separately -- either by spreadsheet or by a separate invoice. I would prefer a separate invoice if we can now in cost point. So we need to set up a new subtask (whichever number is next) -- title of the subtask should be SVE NOD.

TASK 401

Thanks!

Laura

From: Brad Nelson
Sent: Tuesday, January 13, 2009 4:45 PM
To: Mark K. Backus
Cc: Julien Boyance; Laura L. Day
Subject: RE: Attached Image

Mark-
Attached is the signed copy. thank you.

brad

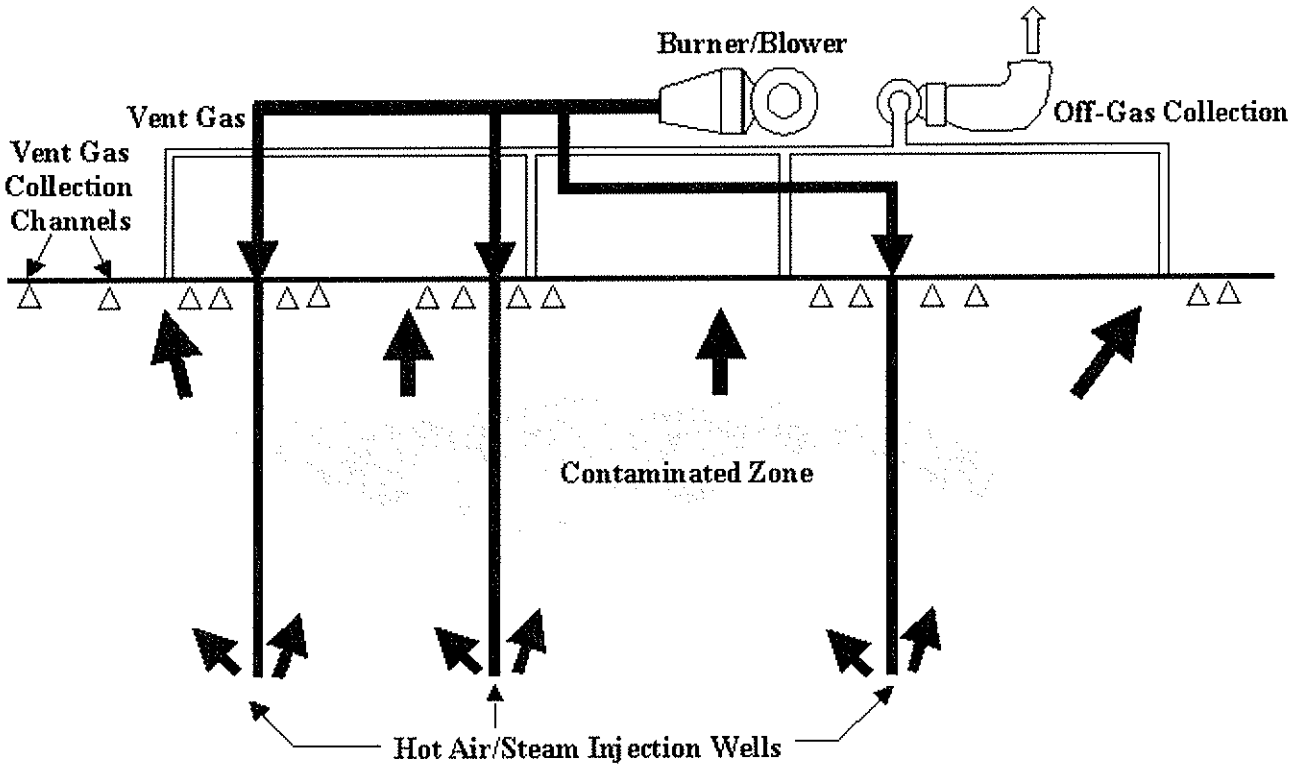
From: Mark K. Backus [mailto:backus_mark_k@lanl.gov]
Sent: Tue 1/13/2009 4:17 PM
To: Brad Nelson
Cc: Julien Boyance
Subject: Fwd: Attached Image

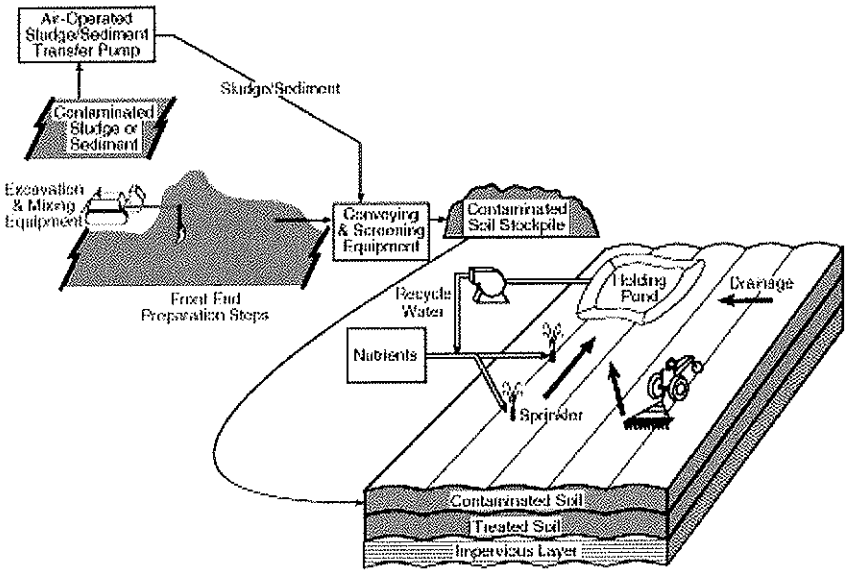
>Brad,

Happy Holiday's please sign and return.....

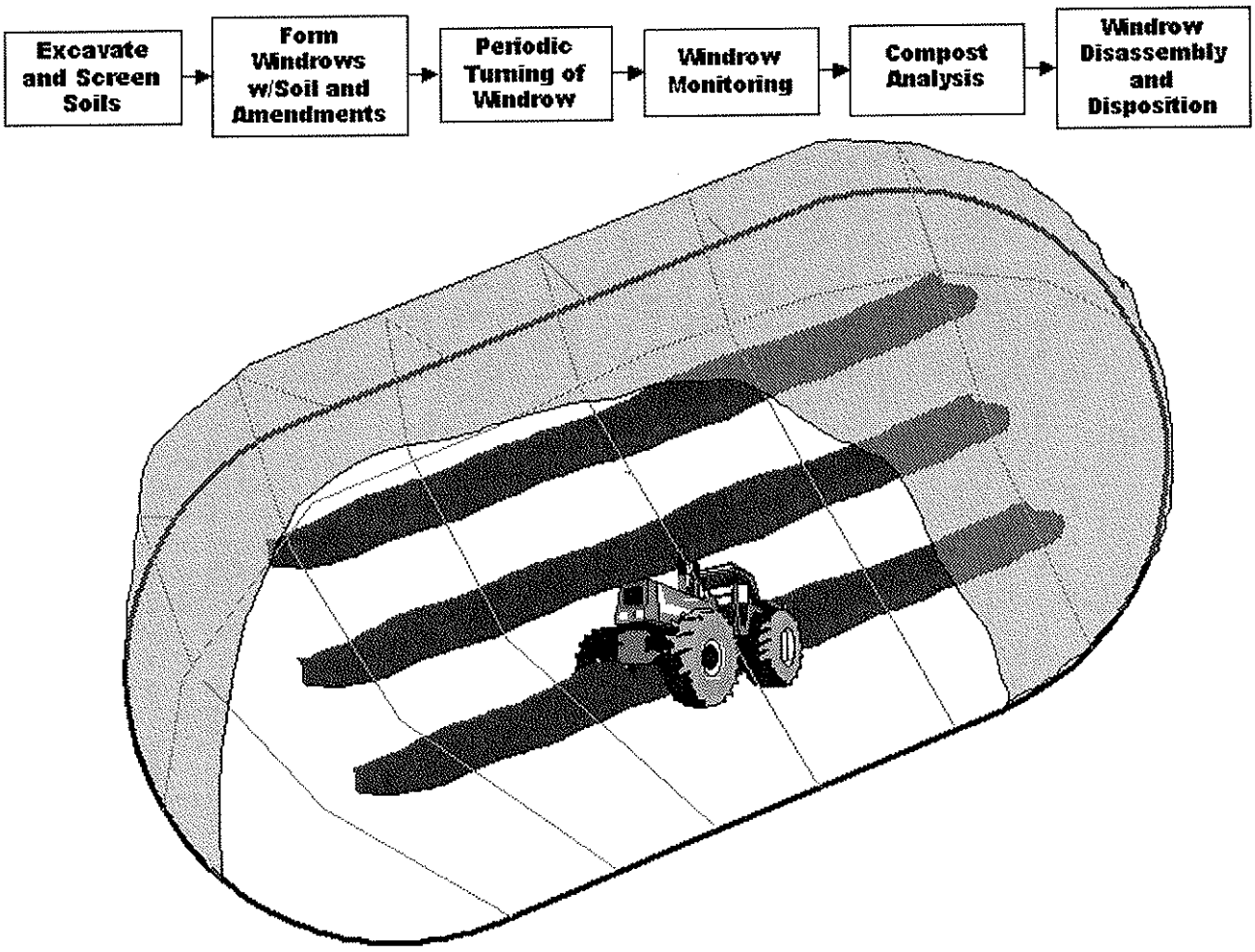
Regards,
Mark

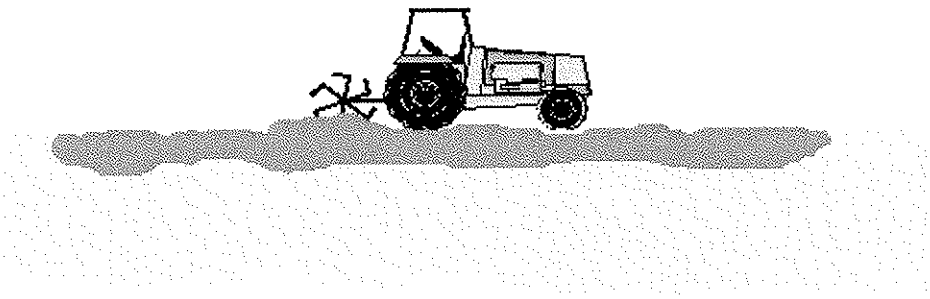
>X-Sieve: CMU Sieve 2.2
>From: asmsubcopier@lanl.gov
>To: "Mark B"
> <backus@lanl.gov>
>Subject: Attached Image
>Date: Tue, 13 Jan 2009 18:09:20 -0500
>X-NIE-2-MailScanner-Information: Please see
>http://network.lanl.gov/email/virus-scan.php
>X-NIE-2-MailScanner: Found to be clean
>X-NIE-2-MailScanner-From: asmsubcopier@lanl.gov
>X-Spam-Status: No
>

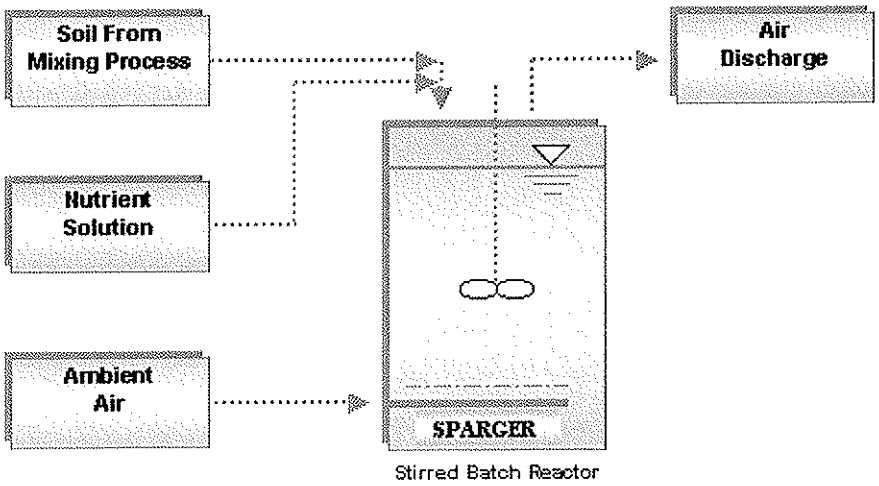

Burner/Blower
Vent Gas
Off-Gas Collection
Vent Gas Collection Channels
Contaminated Zone
Hot Air/Steam Injection Wells



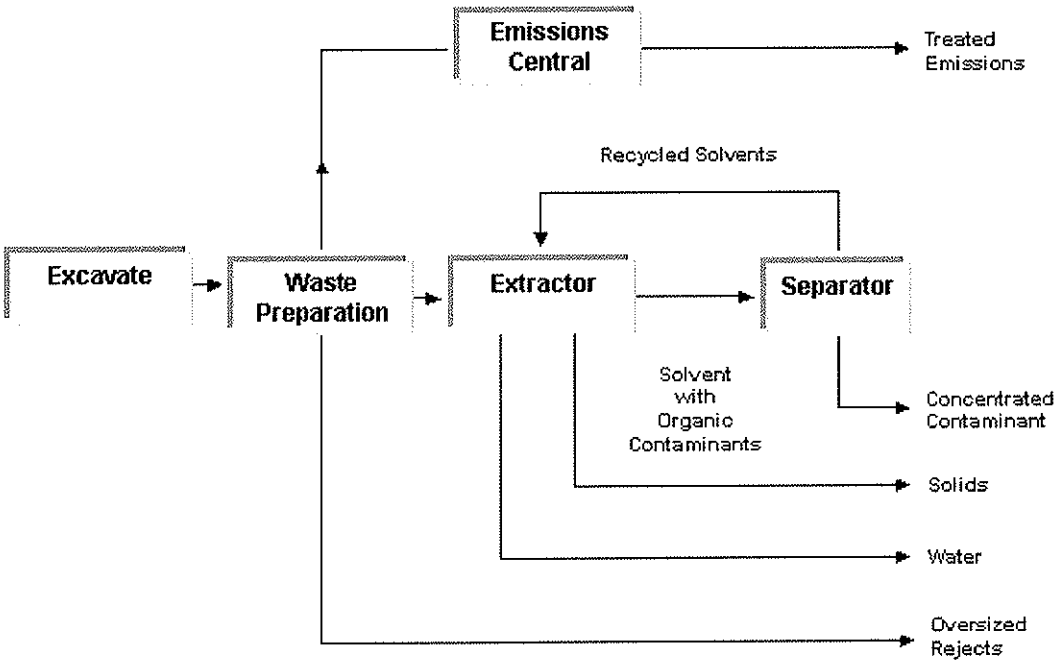
4-11 94P-5121 8/22/94

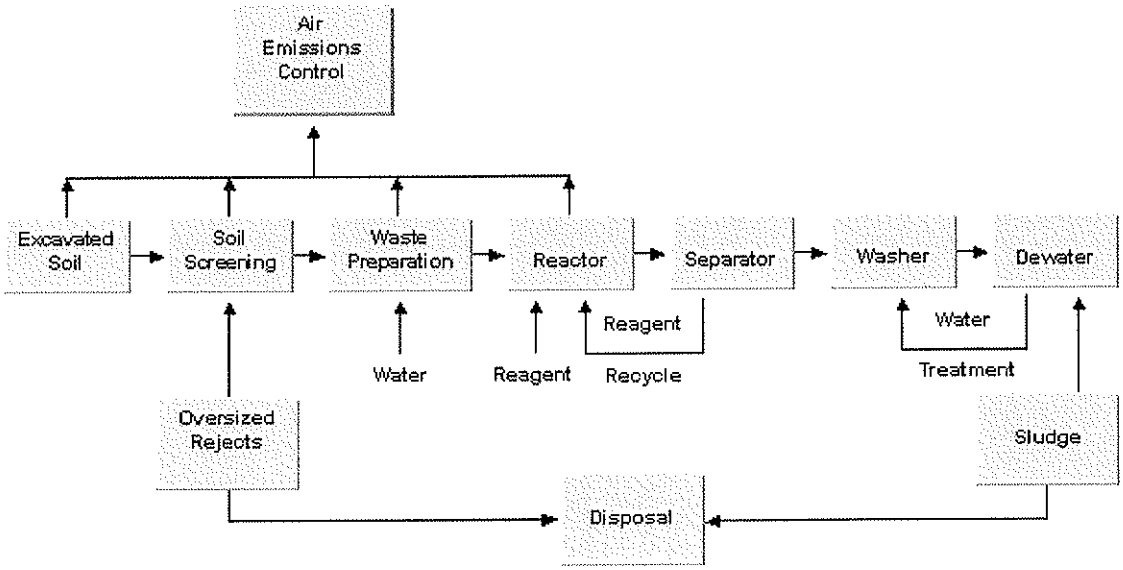

Excavate and Screen Soils
Form Windrows w/Soil and Amendments
Periodic Turning of Windrow
Windrow Monitoring
Compost Analysis
Windrow Disassembly and Disposition

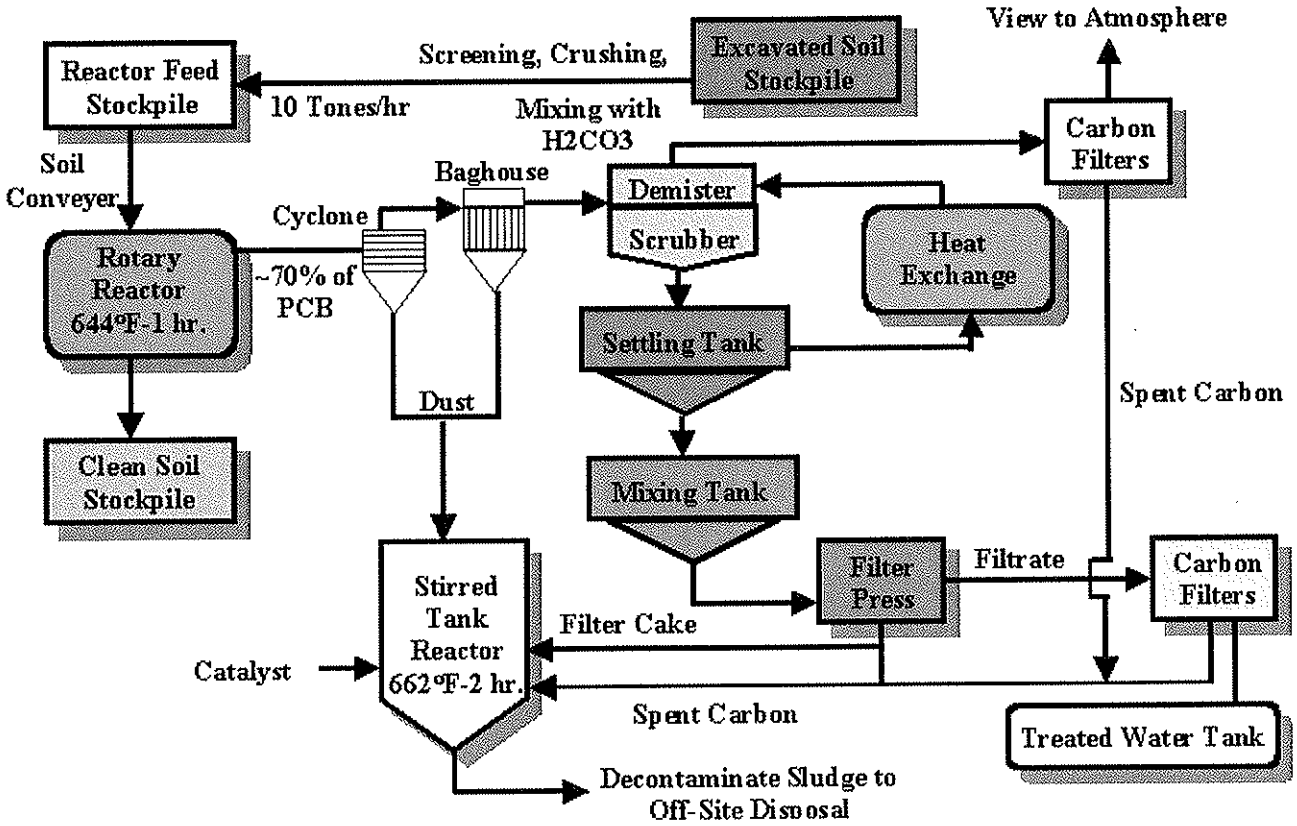


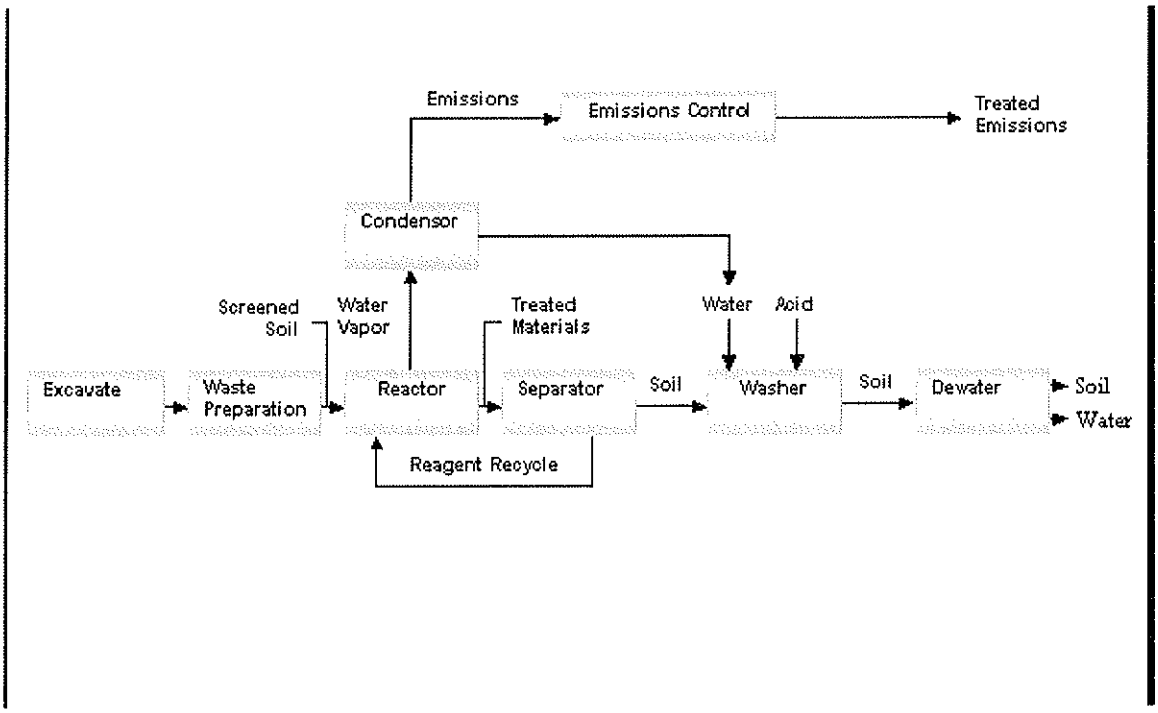


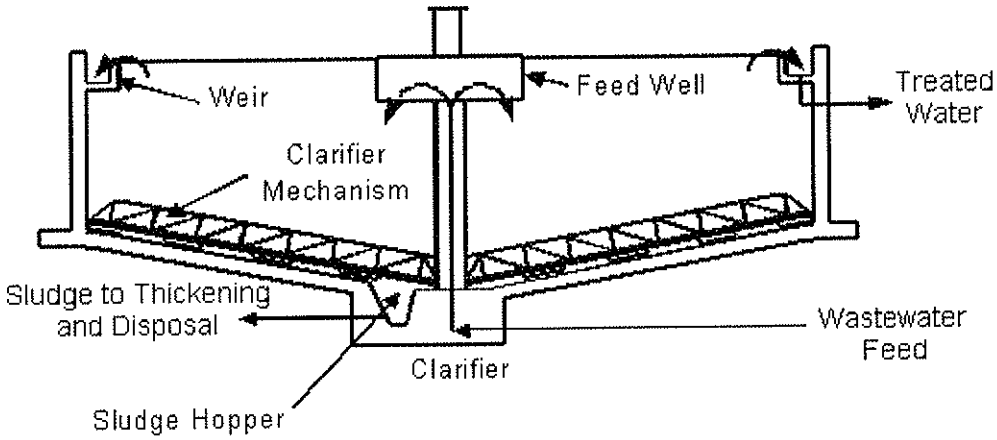
Stirred Batch Reactor

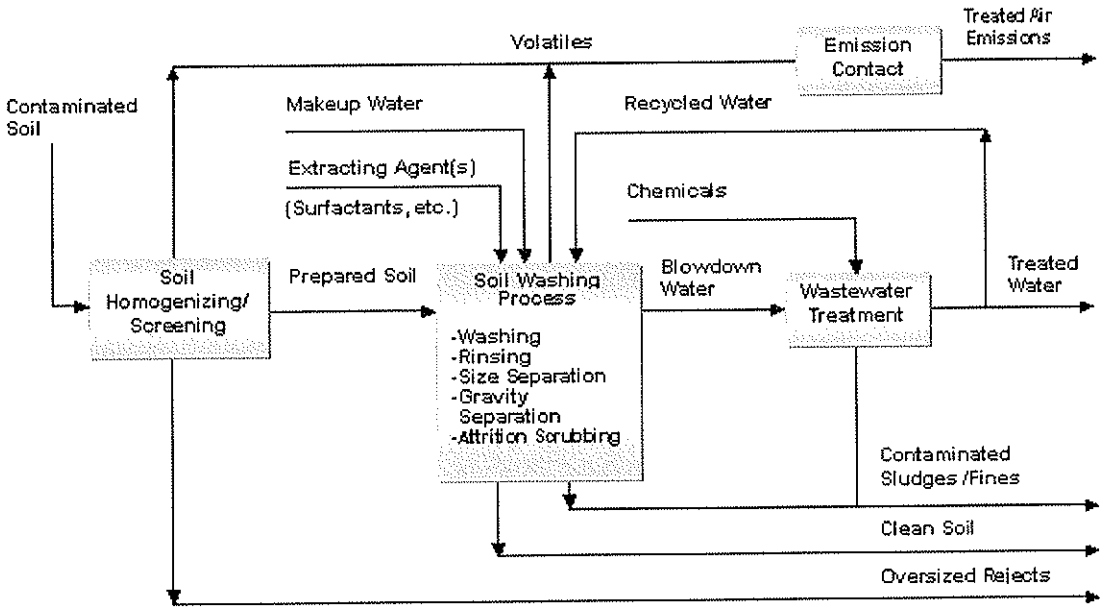

Emissions Central
Treated Emissions
Recycled Solvents
Excavate
Waste Preparation
Extractor
Separator
Solvent with Organic Contaminants
Concentrated Contaminant
Solids
Water
Oversized Rejects

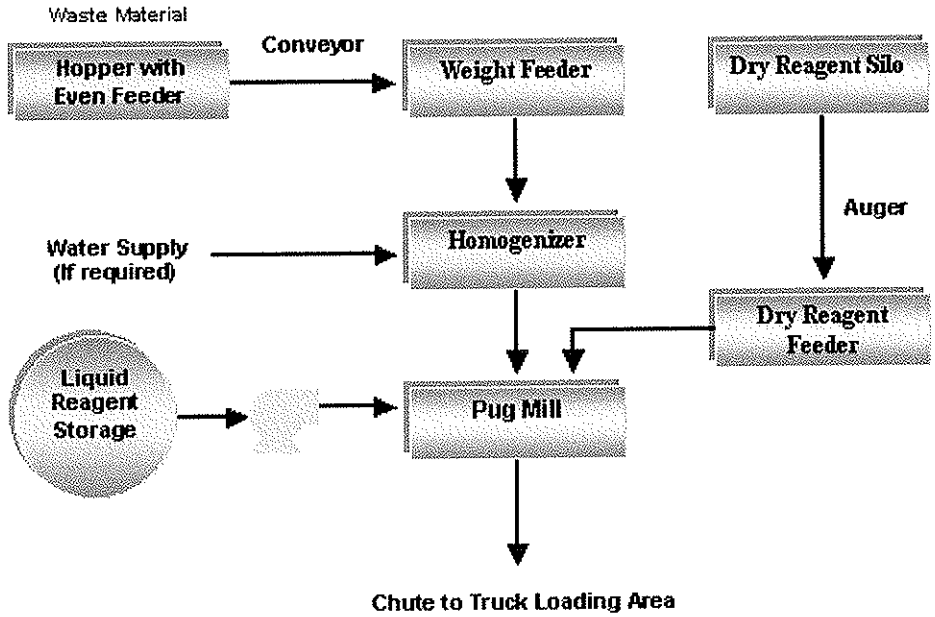

Air Emissions Control
Excavated Soil
Soil Screening
Waste Preparation
Reactor
Separator
Washer
Dewater
Reagent
Water
Water
Reagent
Recycle
Treatment
Oversized Rejects
Sludge
Disposal

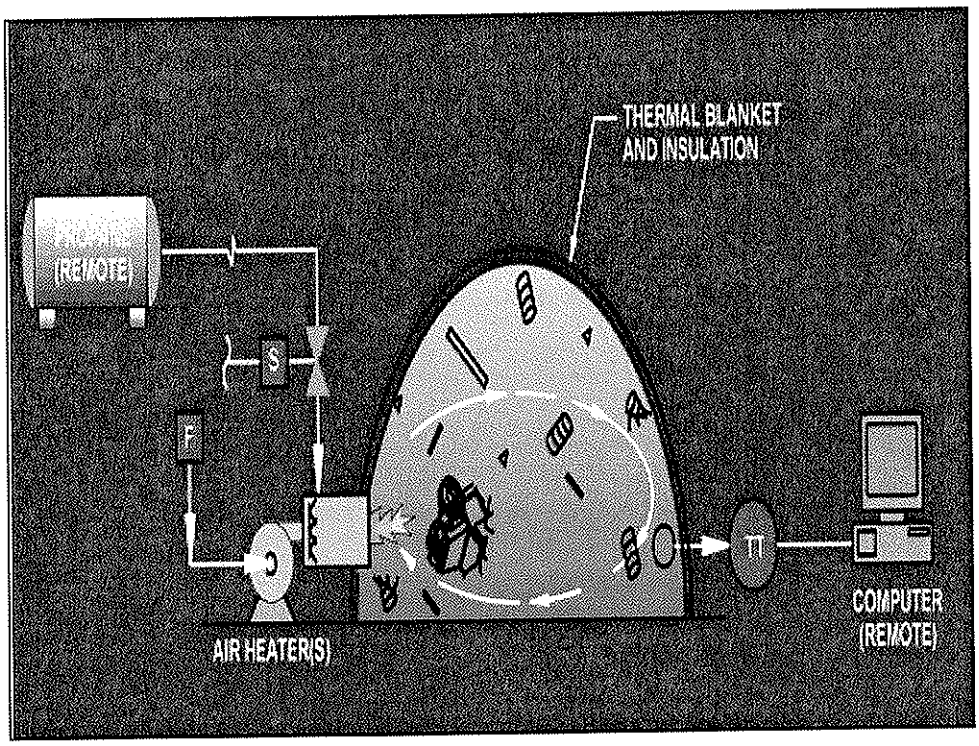

View to Atmosphere
Reactor Feed Stockpile
Screening, Crushing,
Excavated Soil Stockpile
10 Tones/hr
Mixing with H2CO3
Carbon Filters
Soil Conveyer
Baghouse
Demister
Cyclone
Scrubber
Heat Exchange
Rotary Reactor 644°F-1 hr.
~70% of PCB
Settling Tank
Spent Carbon
Dust
Clean Soil Stockpile
Mixing Tank
Filter Press
Filtrate
Carbon Filters
Stirred Tank Reactor 662°F-2 hr.
Filter Cake
Catalyst
Spent Carbon
Treated Water Tank
Decontaminate Sludge to Off-Site Disposal

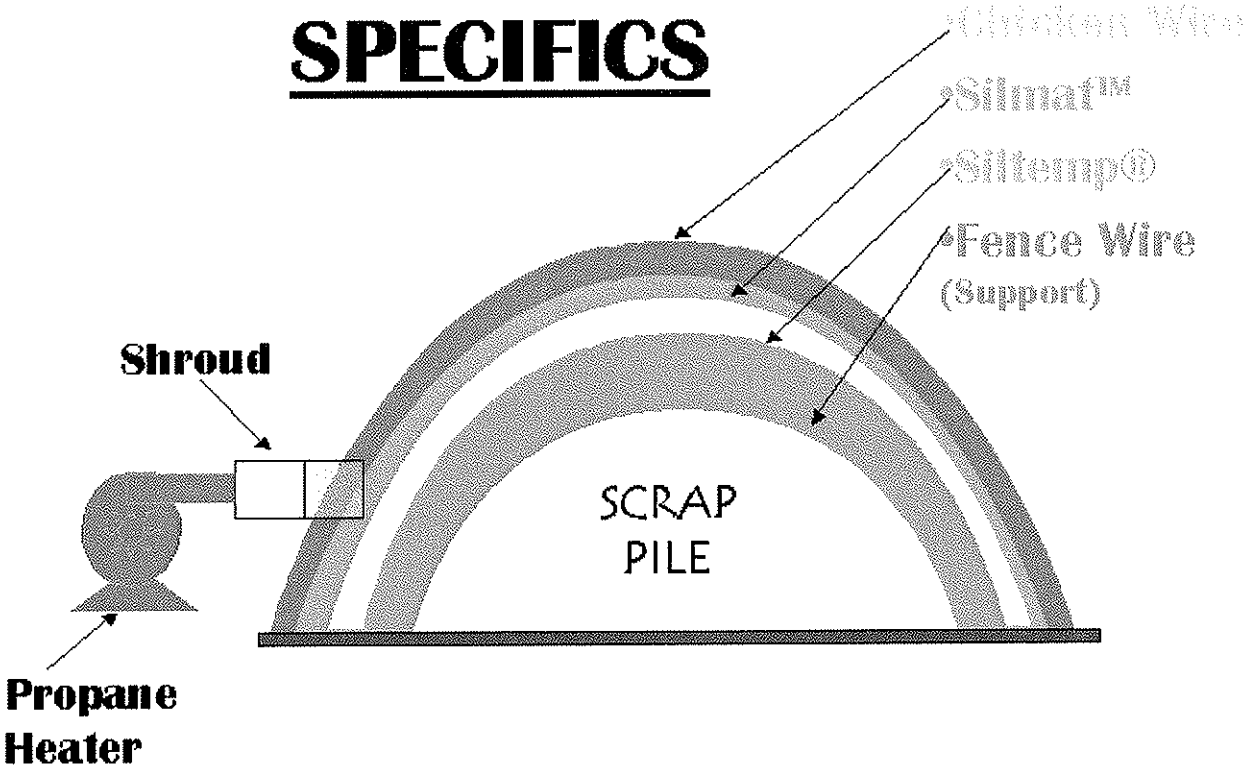

Emissions
Emissions Control
Treated Emissions
Condensor
Screened Soil
Water Vapor
Treated Materials
Water
Acid
Excavate
Waste Preparation
Reactor
Separator
Soil
Washer
Soil
Dewater
Soil
Water
Reagent Recycle

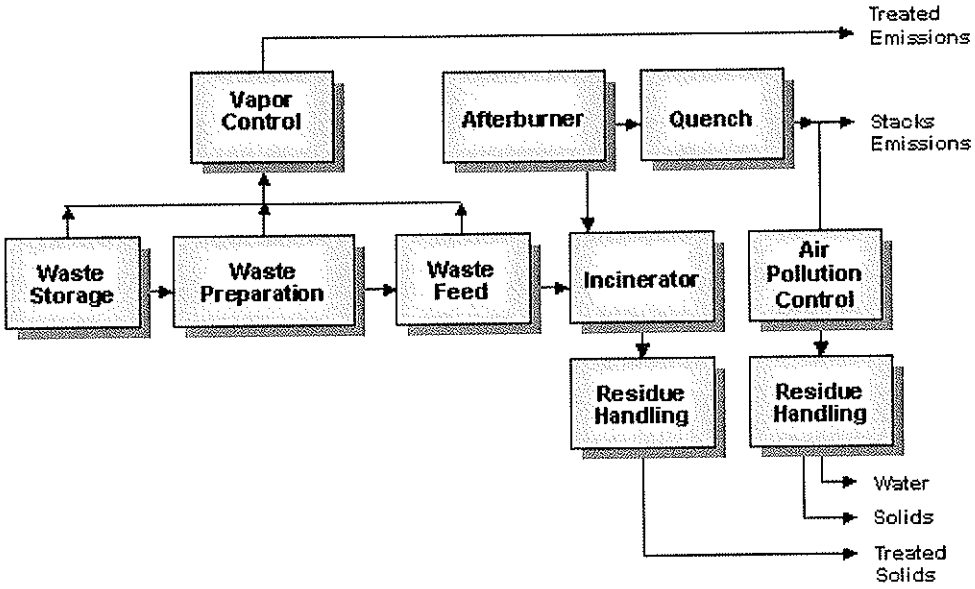

Weir
Feed Well
Treated Water
Clarifier Mechanism
Sludge to Thickening and Disposal
Wastewater Feed
Clarifier
Sludge Hopper

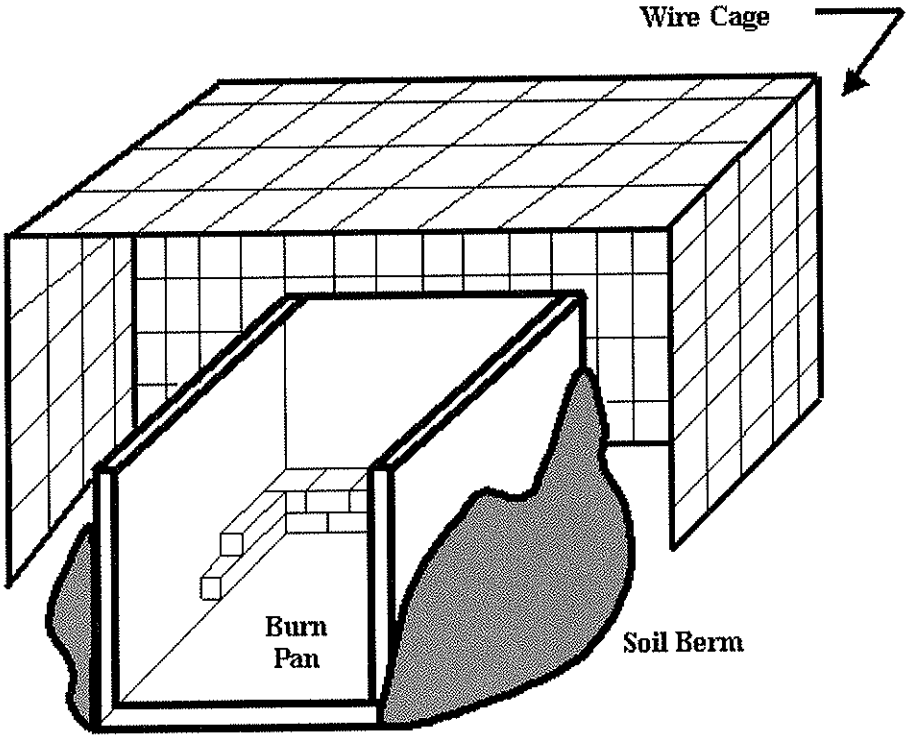

Volatiles
Emission Contact
Treated Air Emissions
Contaminated Soil
Makeup Water
Recycled Water
Extracting Agent(s)
(Surfactants, etc.)
Chemicals
Soil Homogenizing/ Screening
Prepared Soil
Soil Washing Process
-Washing
-Rinsing
-Size Separation
-Gravity Separation
-Attrition Scrubbing
Blowdown Water
Wastewater Treatment
Treated Water
Contaminated Sludges /Fines
Clean Soil
Oversized Rejects

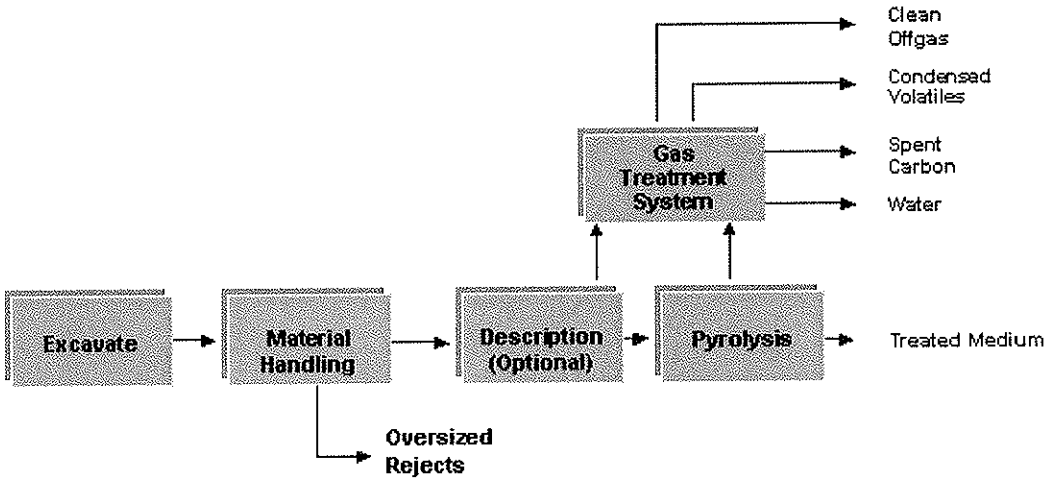

Waste Material
Hopper with Even Feeder
Conveyor
Weight Feeder
Dry Reagent Silo
Auger
Water Supply (If required)
Homogenizer
Dry Reagent Feeder
Liquid Reagent Storage
Pug Mill
Chute to Truck Loading Area

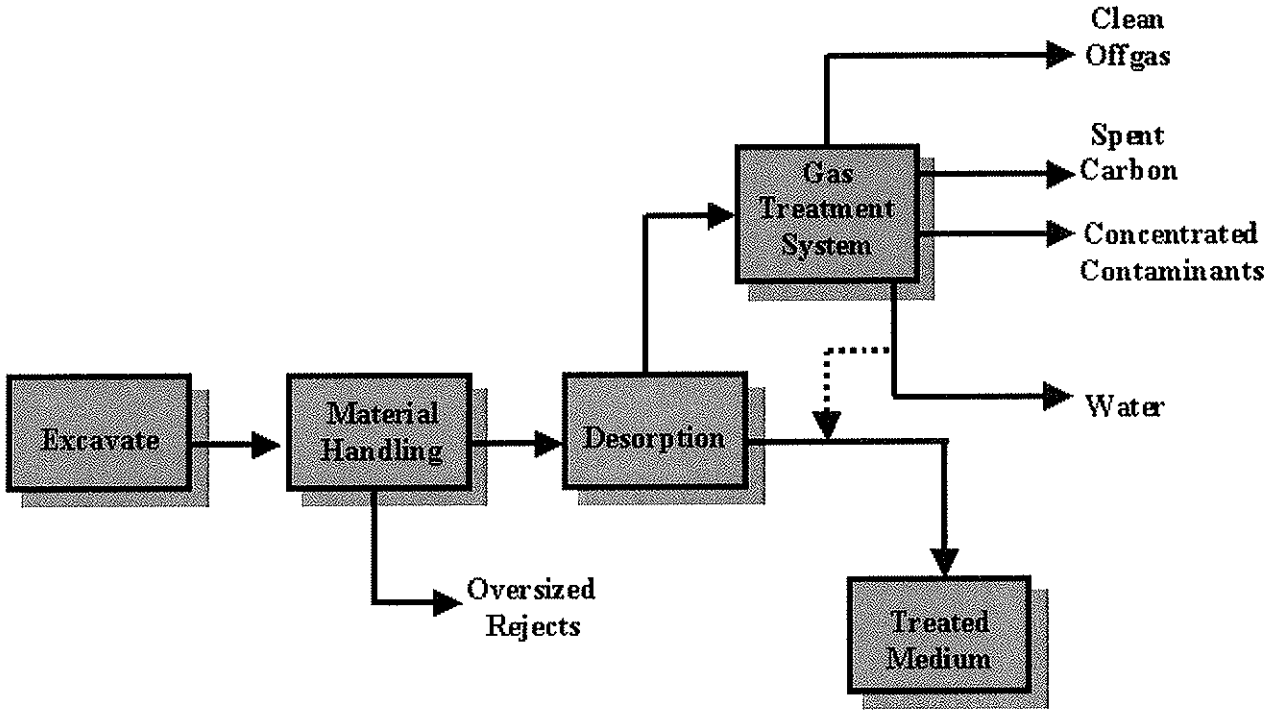

THERMAL BLANKET
AND INSULATION
(REMOTE)
S
F
E
C
AIR HEATER(S)
TT
COMPUTER
(REMOTE)

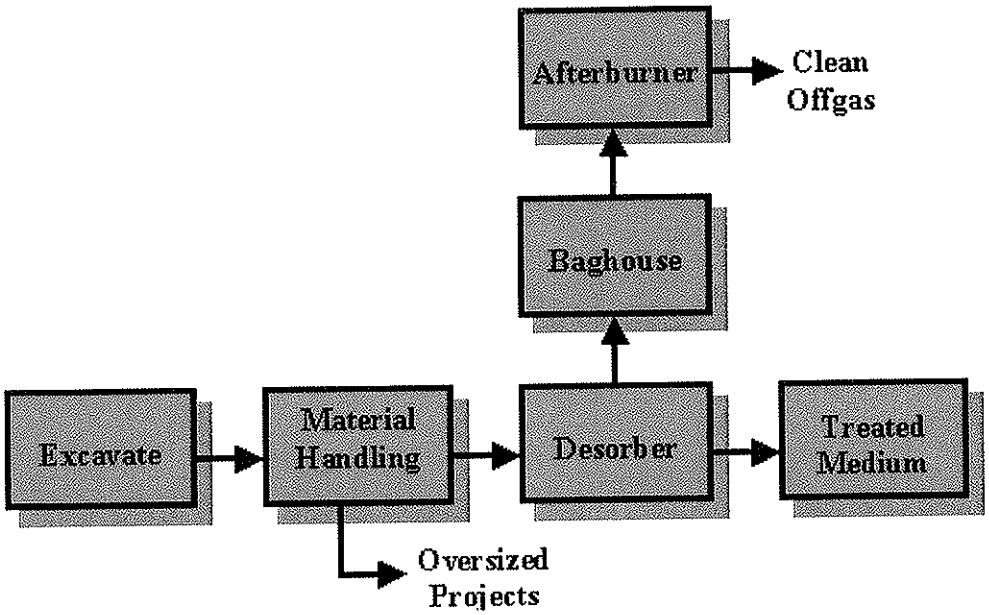

SPECIFICS
•Chicken Wire
•Silmat™
•Siltemp®
•Fence Wire
(Support)
Shroud
SCRAP
PILE
Propane
Heater

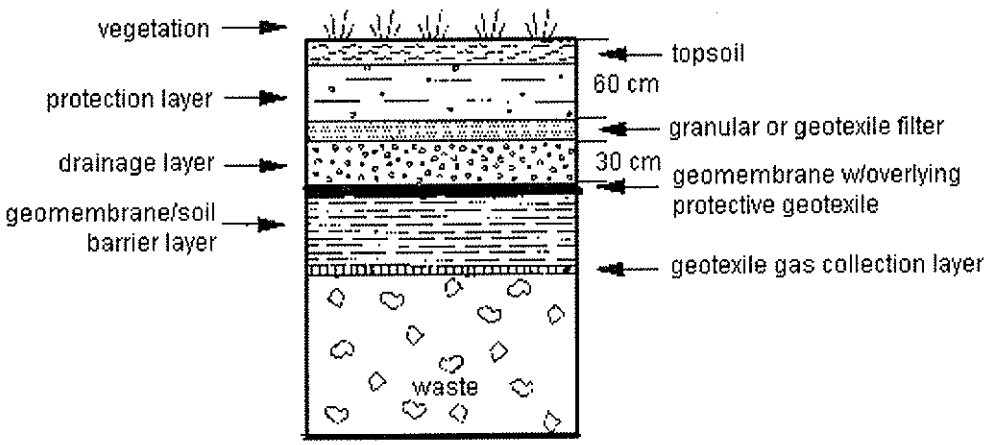

Treated Emissions
Vapor Control
Afterburner
Quench
Stacks Emissions
Waste Storage
Waste Preparation
Waste Feed
Incinerator
Air Pollution Control
Residue Handling
Residue Handling
Water
Solids
Treated Solids

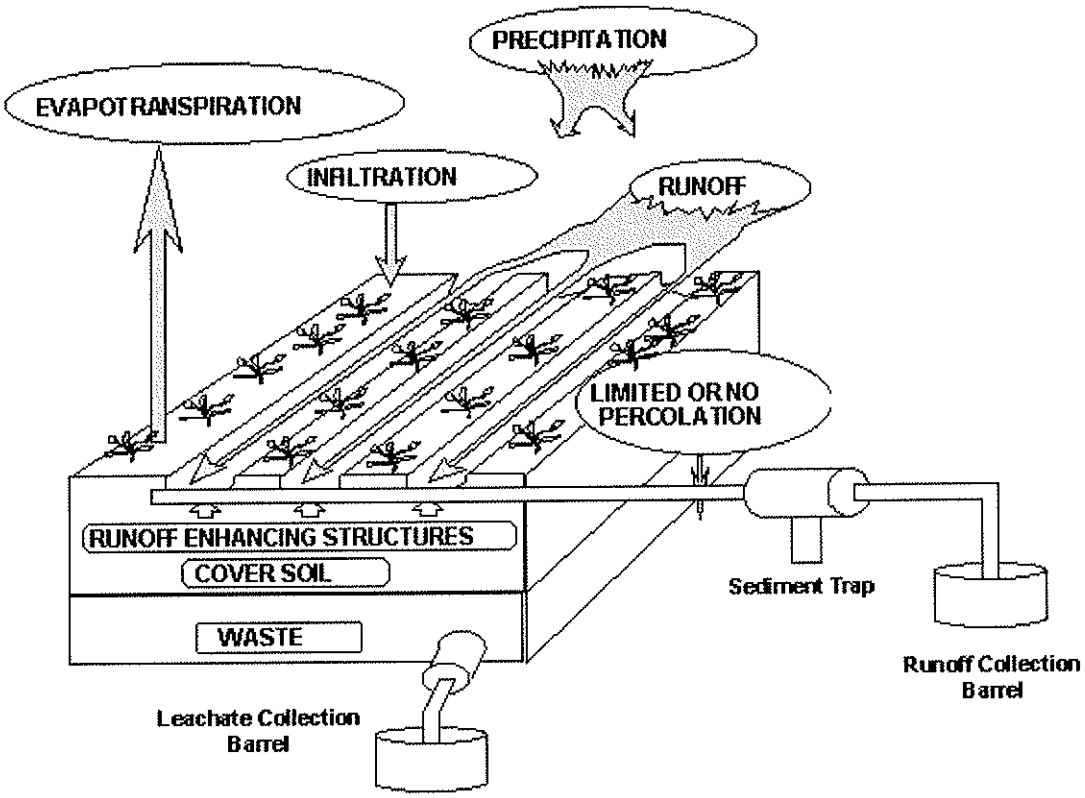

Wire Cage
Burn
Pan
Soil Berm

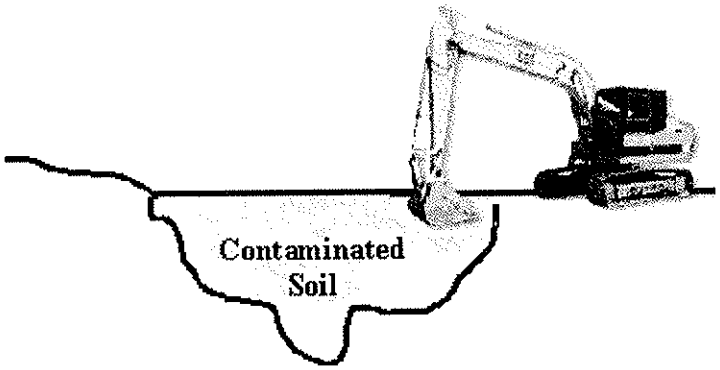

Clean
Offgas
Condensed
Volatiles
Gas
Treatment
System
Spent
Carbon
Water
Excavate
Material
Handling
Description
(Optional)
Pyrolysis
Treated Medium
Oversized
Rejects

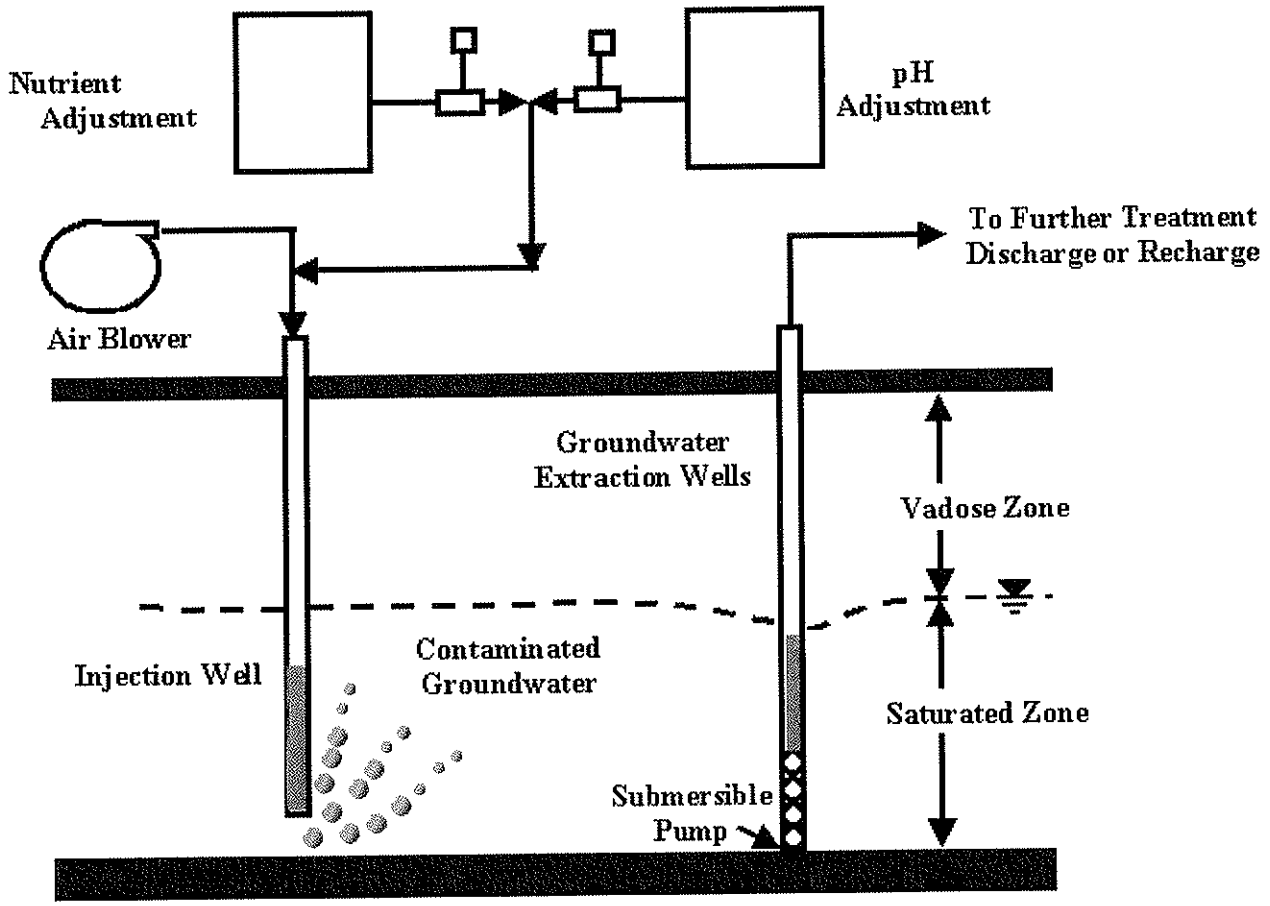

Clean
Offgas
Spent
Carbon
Gas
Treatment
System
Concentrated
Contaminants
Water
Excavate
Material
Handling
Desorption
Oversized
Rejects
Treated
Medium

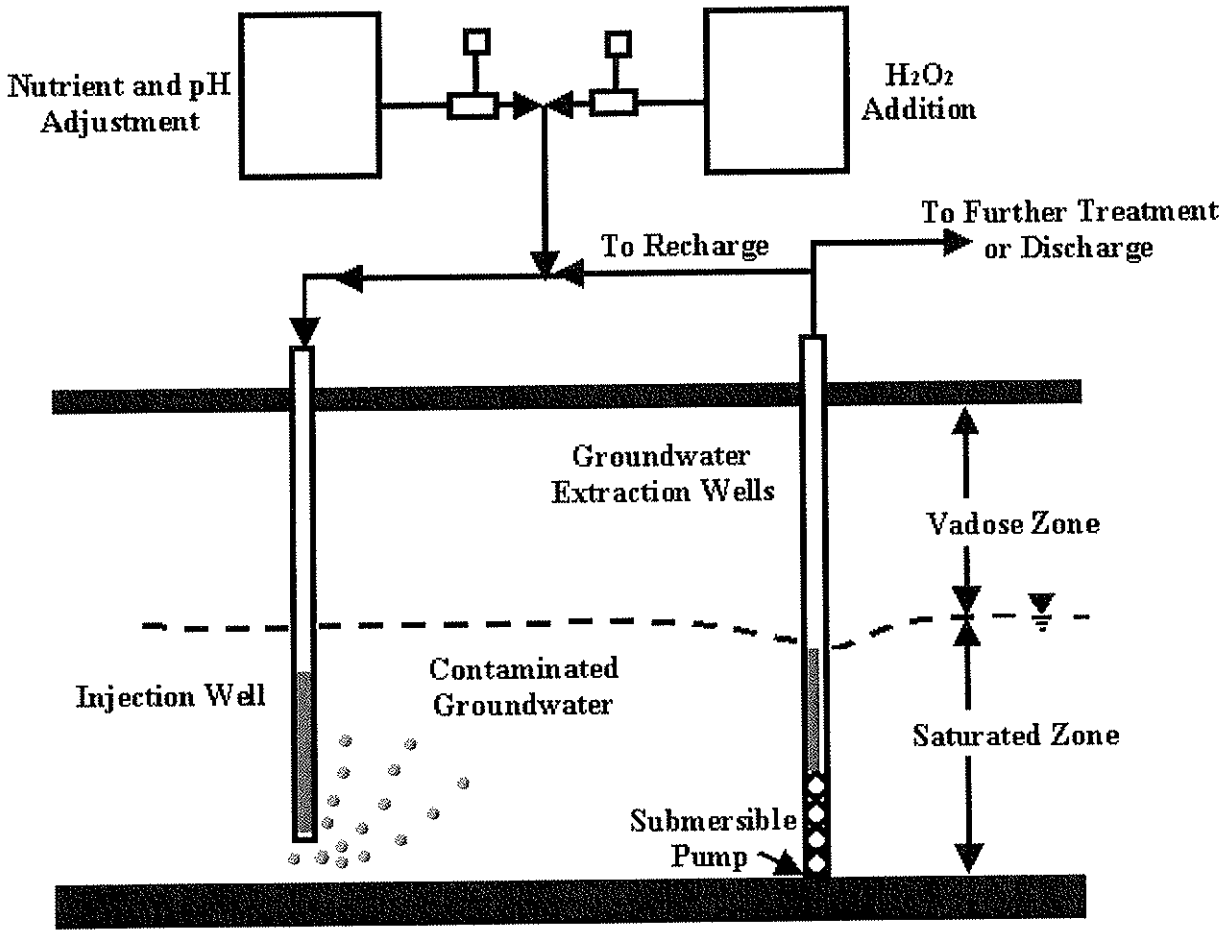

Afterburner
Clean Offgas
Baghouse
Excavate
Material Handling
Desorber
Treated Medium
Oversized Projects

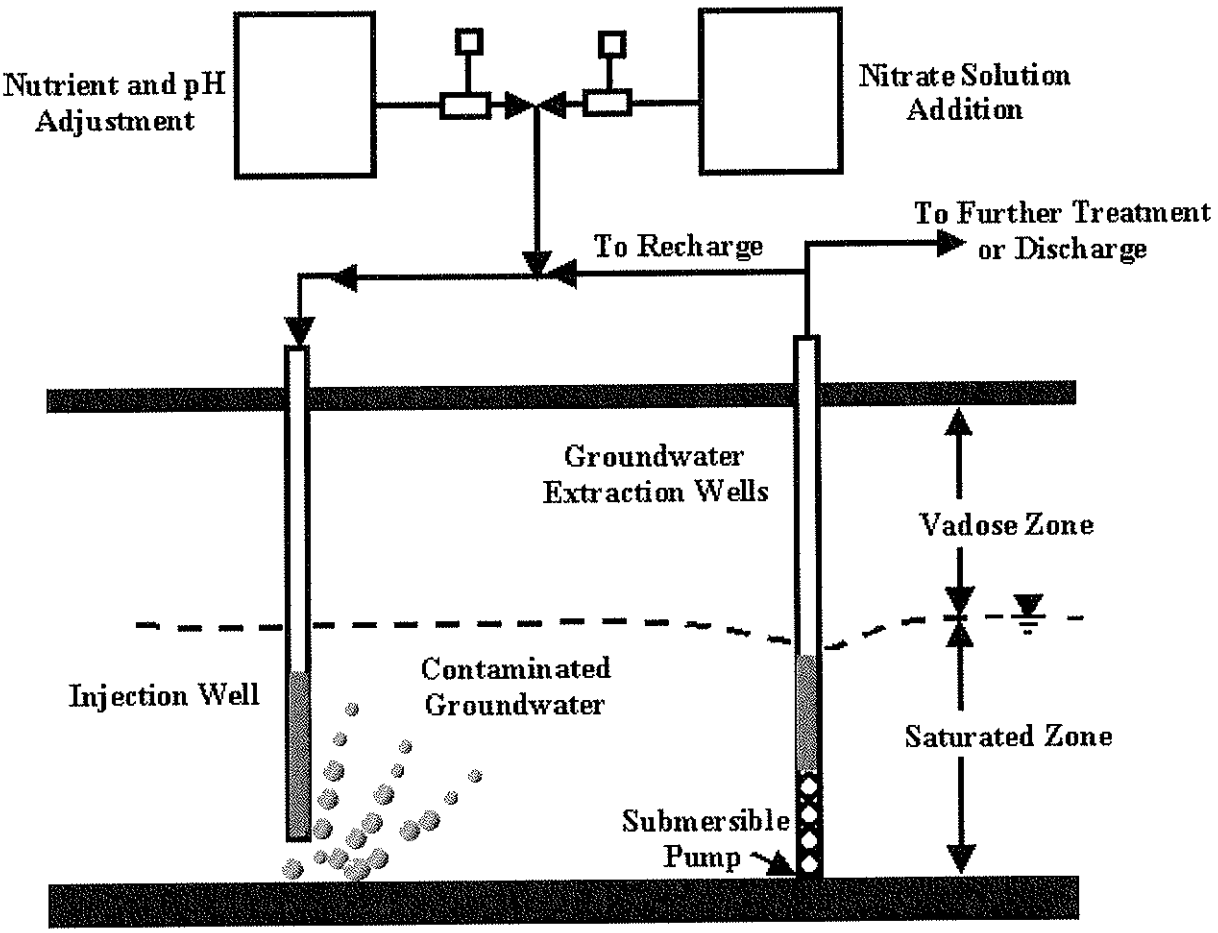

vegetation
protection layer
drainage layer
geomembrane/soil
barrier layer
topsoil
60 cm
granular or geotexile filter
30 cm
geomembrane w/overlying
protective geotexile
geotexile gas collection layer
waste

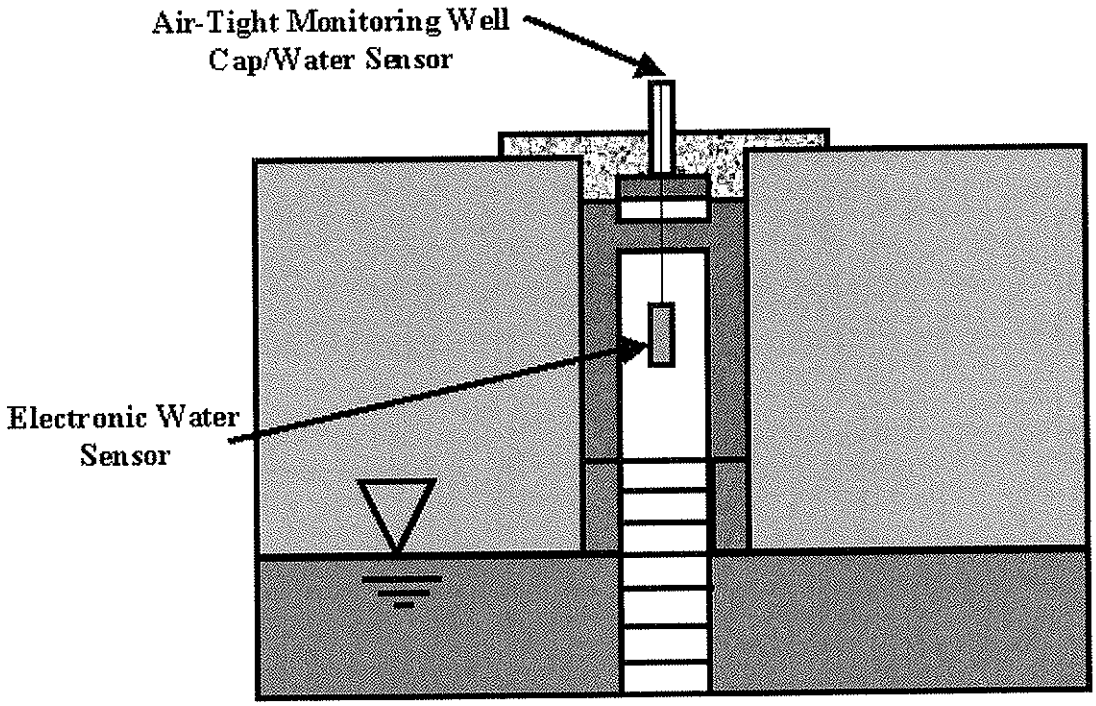

PRECIPITATION
EVAPOTRANSPIRATION
INFILTRATION
RUNOFF
LIMITED OR NO PERCOLATION
RUNOFF ENHANCING STRUCTURES
COVER SOIL
WASTE
Sediment Trap
Runoff Collection Barrel
Leachate Collection Barrel

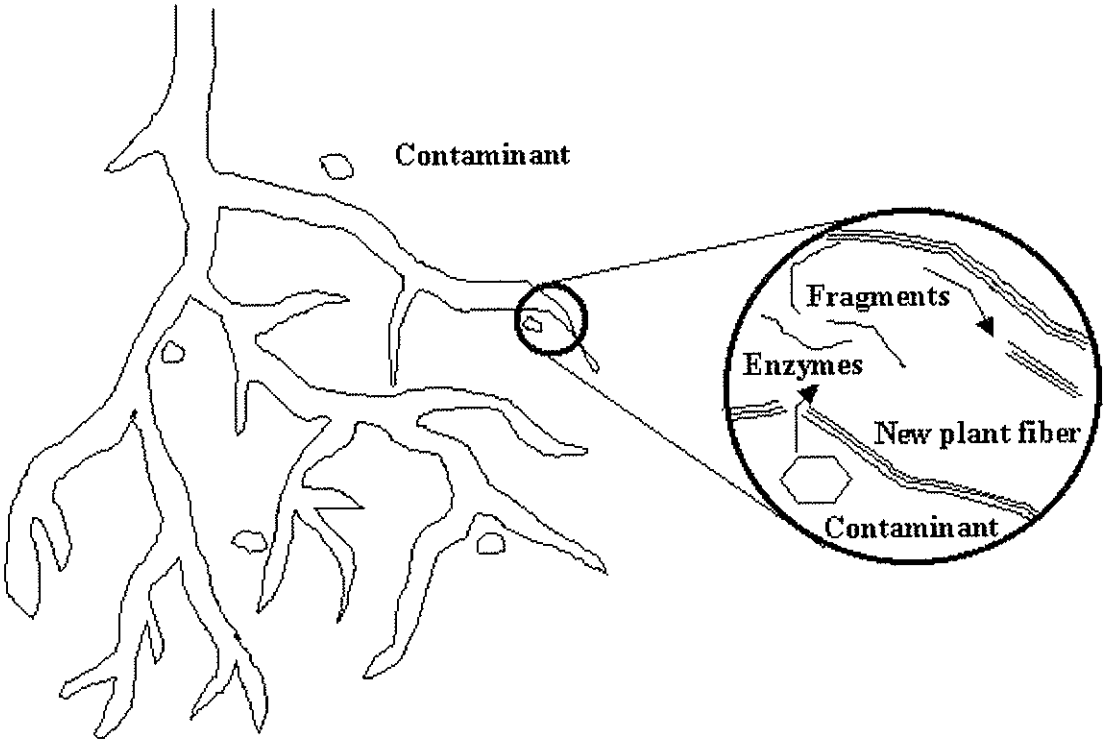

Contaminated
Soil

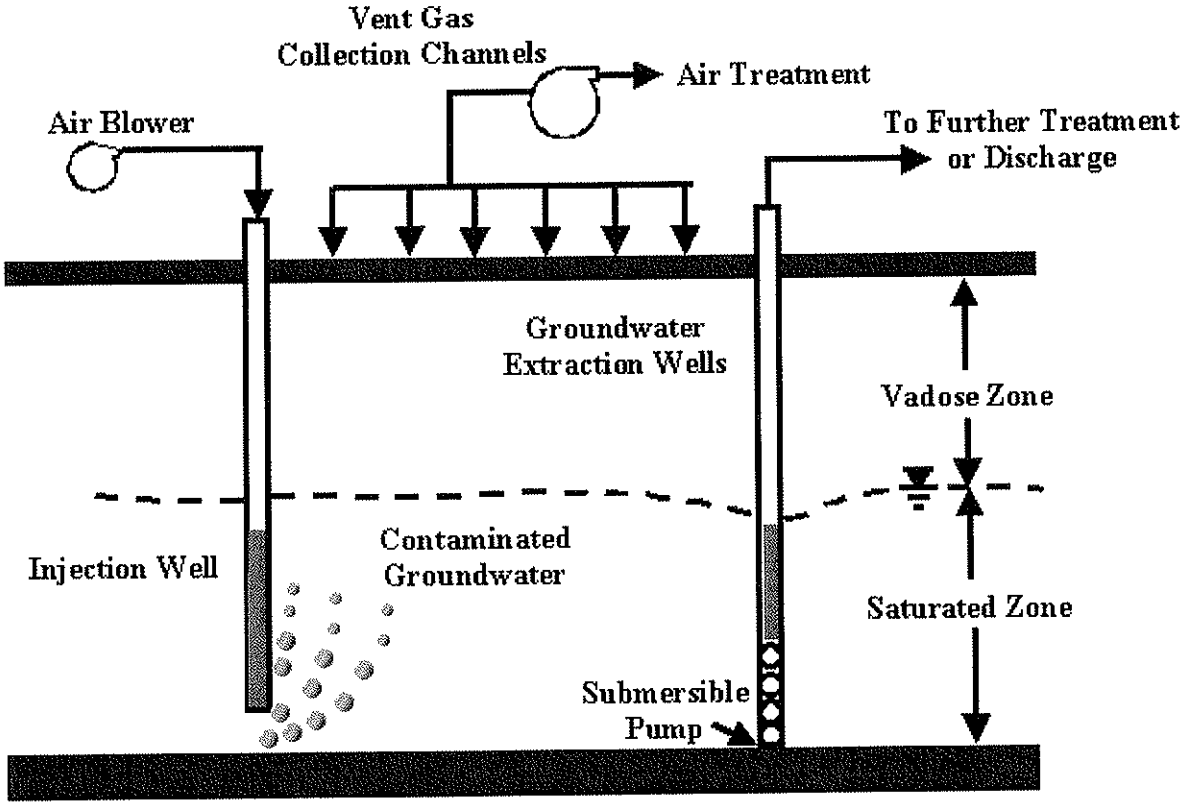

Nutrient
Adjustment
pH
Adjustment
To Further Treatment
Discharge or Recharge
Air Blower
Groundwater
Extraction Wells
Vadose Zone
Injection Well
Contaminated
Groundwater
Saturated Zone
Submersible
Pump

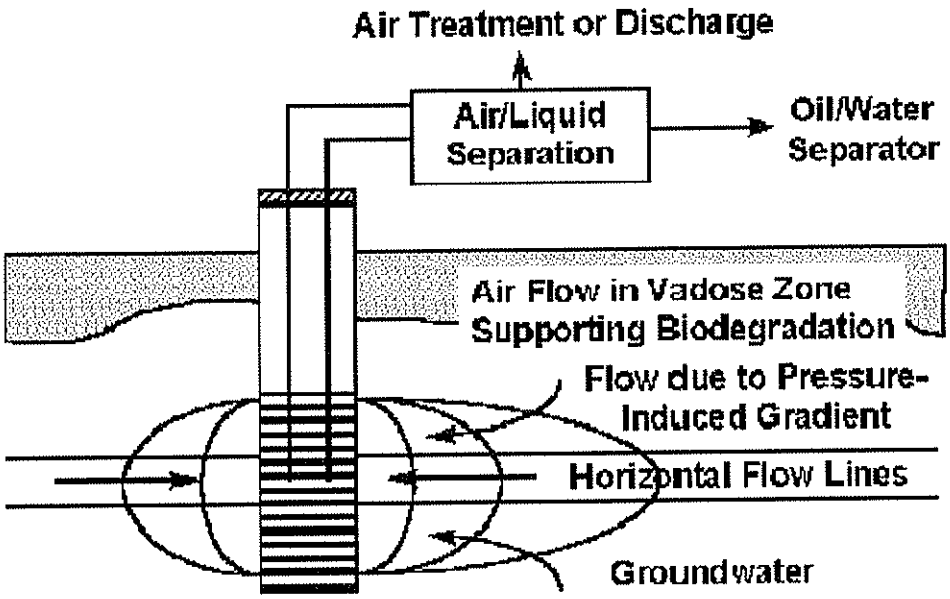

Nutrient and pH Adjustment
H_2O_2 Addition
To Recharge
To Further Treatment or Discharge
Groundwater Extraction Wells
Vadose Zone
Injection Well
Contaminated Groundwater
Saturated Zone
Submersible Pump

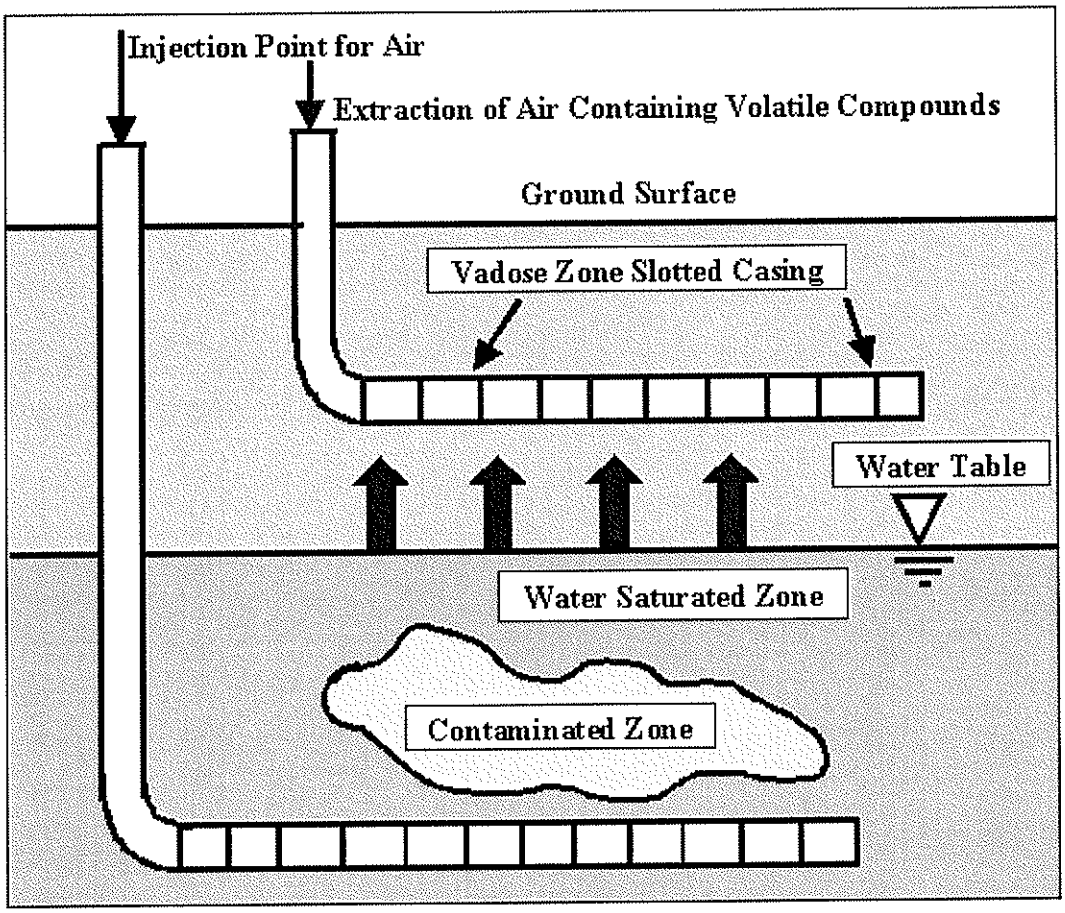

Nutrient and pH Adjustment
Nitrate Solution Addition
To Recharge
To Further Treatment or Discharge
Groundwater Extraction Wells
Vadose Zone
Injection Well
Contaminated Groundwater
Saturated Zone
Submersible Pump

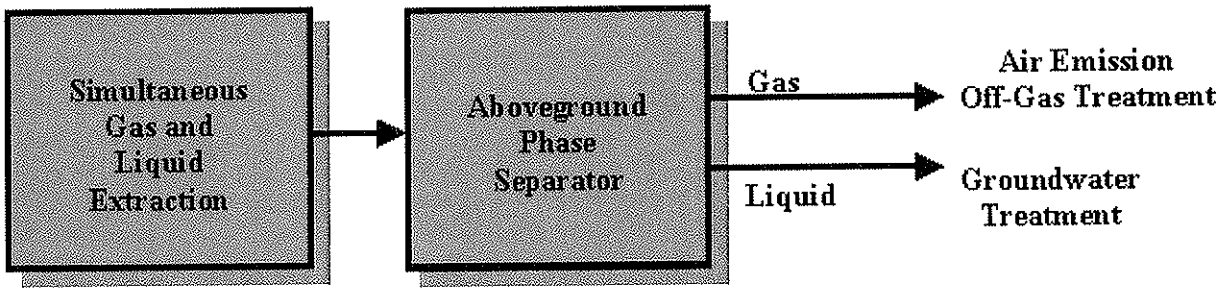

Air-Tight Monitoring Well
Cap/Water Sensor
Electronic Water
Sensor

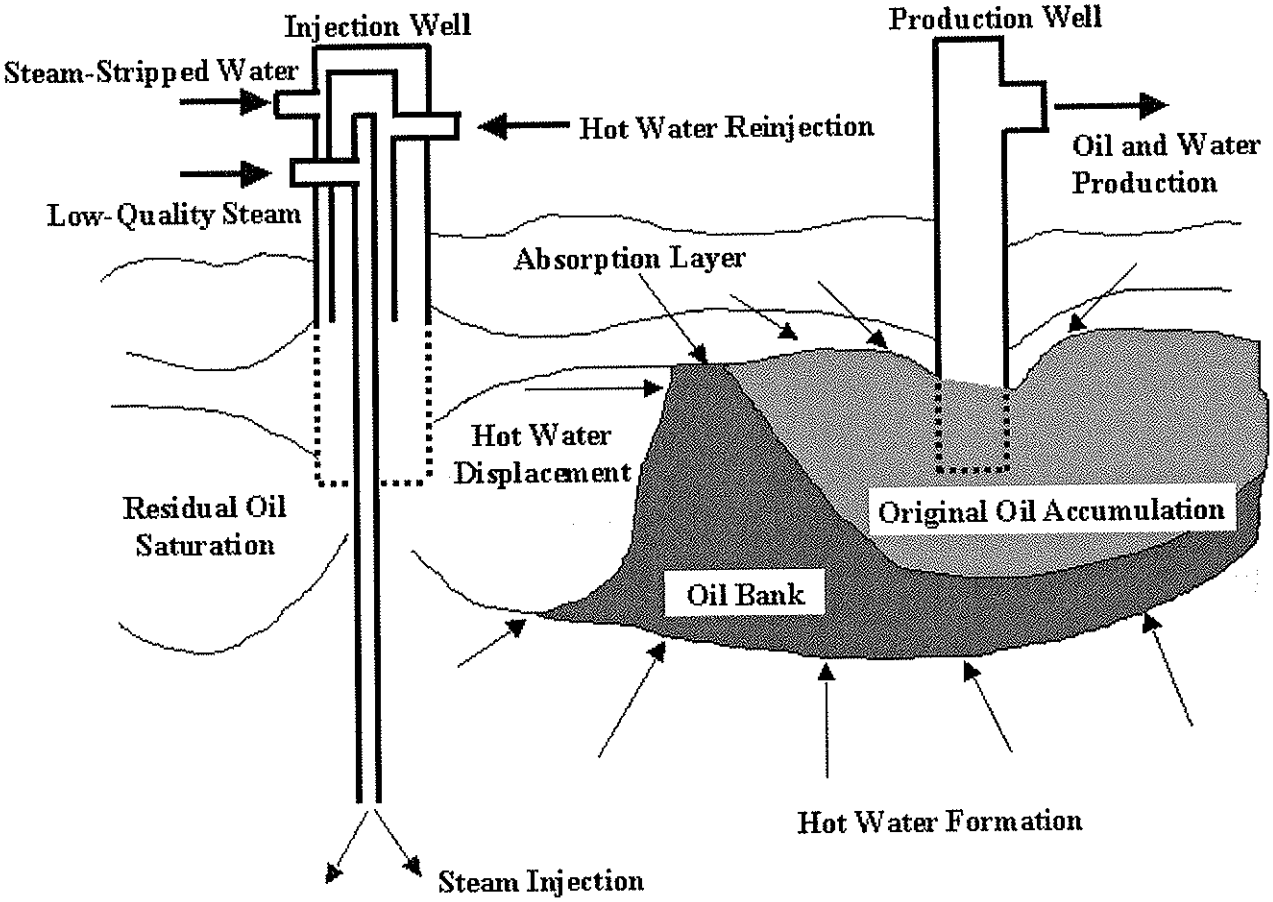

Contaminant
Fragments
Enzymes
New plant fiber
Contaminant

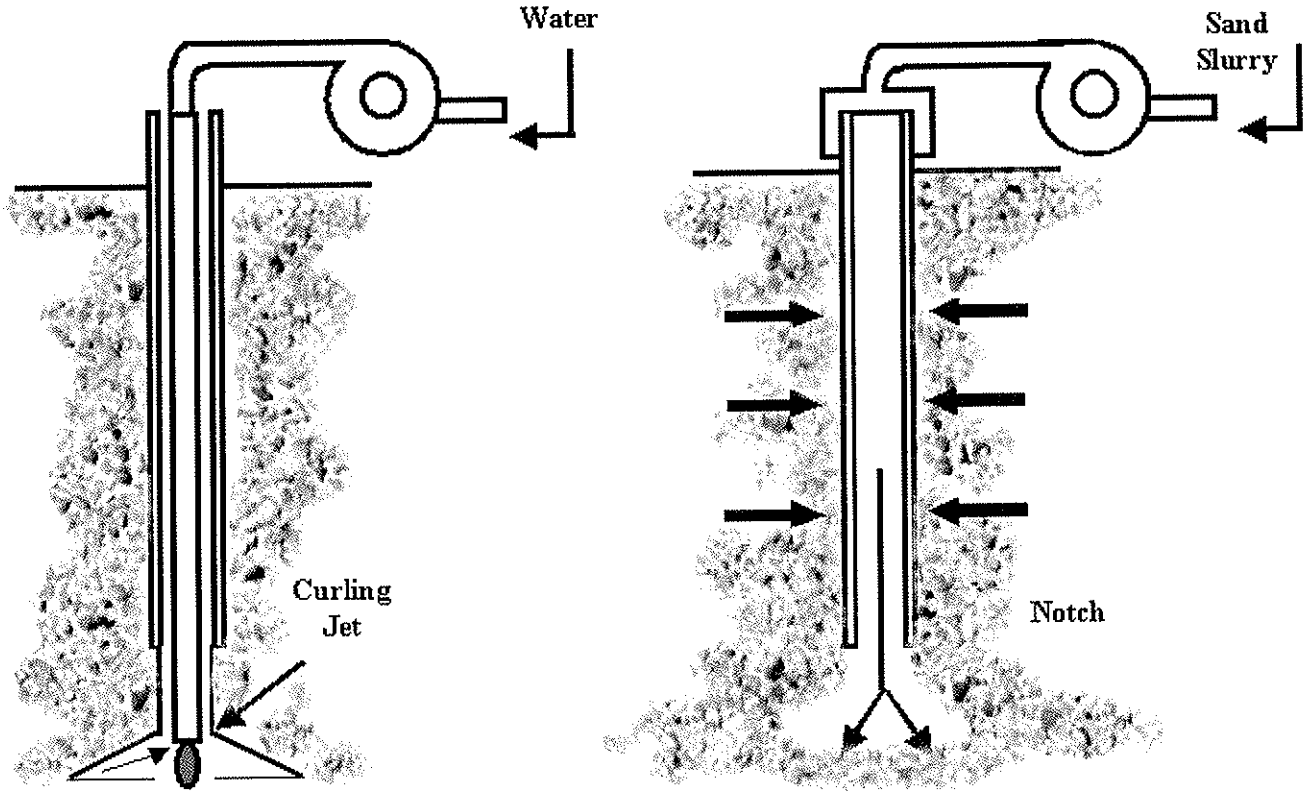

Vent Gas
Collection Channels
Air Treatment
Air Blower
To Further Treatment
or Discharge
Groundwater
Extraction Wells
Vadose Zone
Injection Well
Contaminated
Groundwater
Saturated Zone
Submersible
Pump

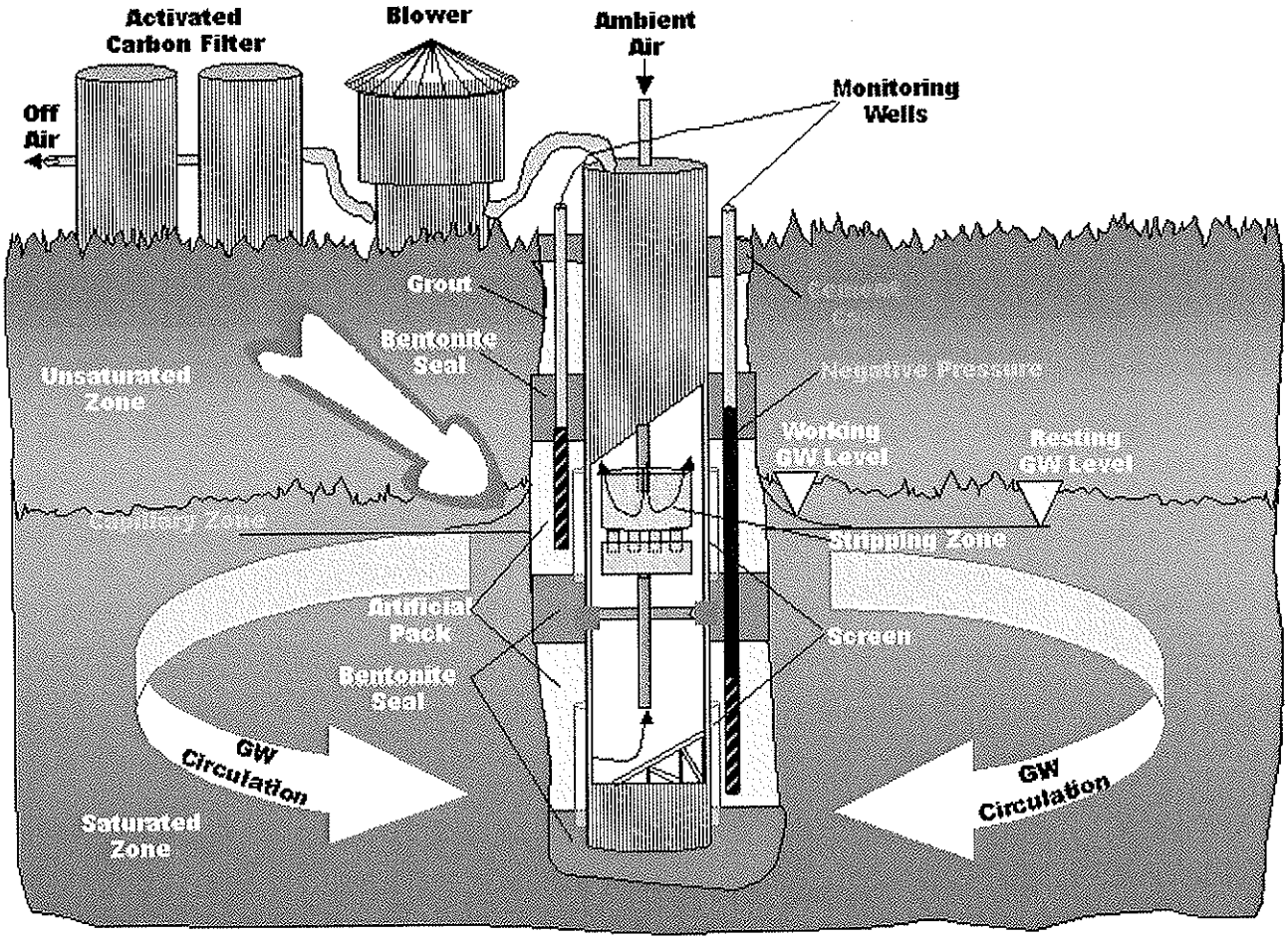

Air Treatment or Discharge
Air/Liquid Separation
Oil/Water Separator
Air Flow in Vadose Zone Supporting Biodegradation
Flow due to Pressure-Induced Gradient
Horizontal Flow Lines
Groundwater

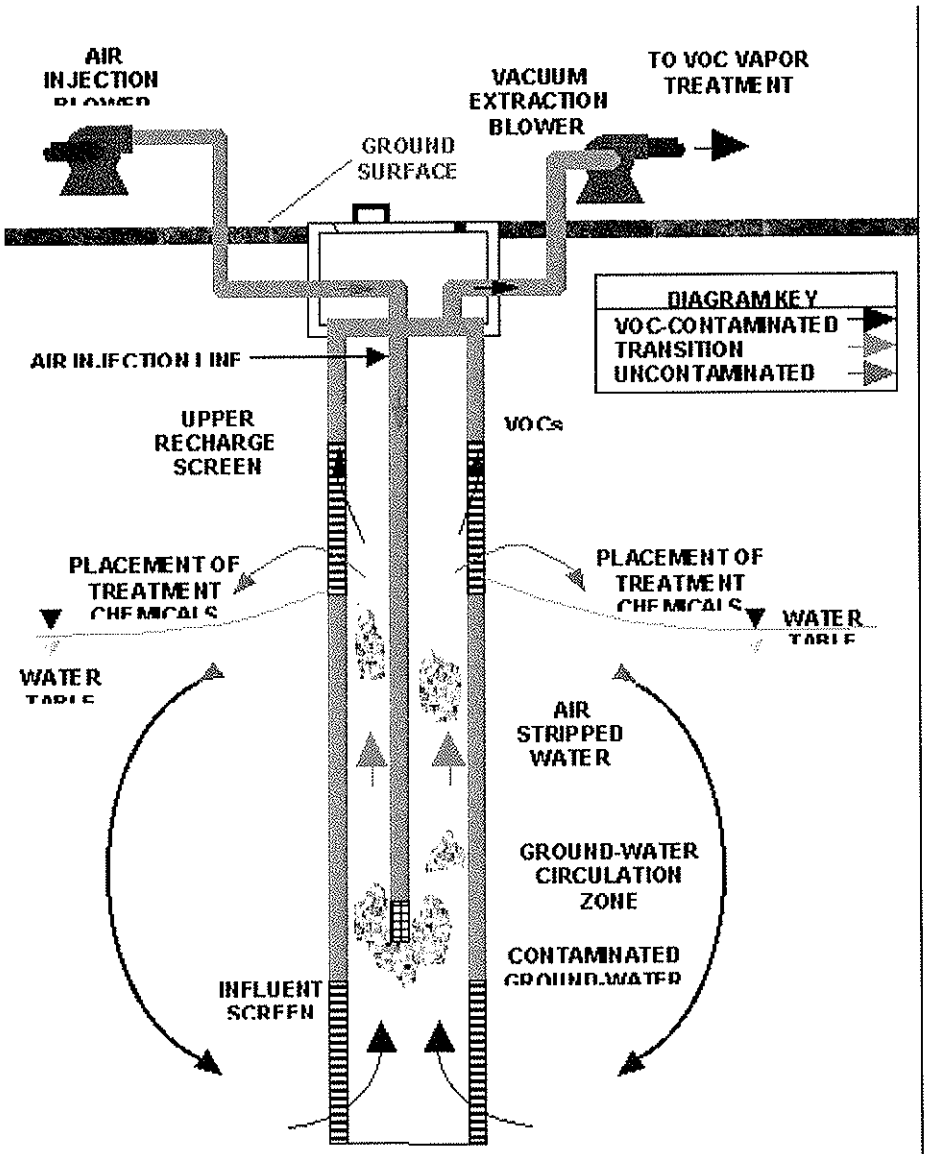

Injection Point for Air
Extraction of Air Containing Volatile Compounds
Ground Surface
Vadose Zone Slotted Casing
Water Table
Water Saturated Zone
Contaminated Zone


Simultaneous Gas and Liquid Extraction
Aboveground Phase Separator
Gas
Liquid
Air Emission Off-Gas Treatment
Groundwater Treatment

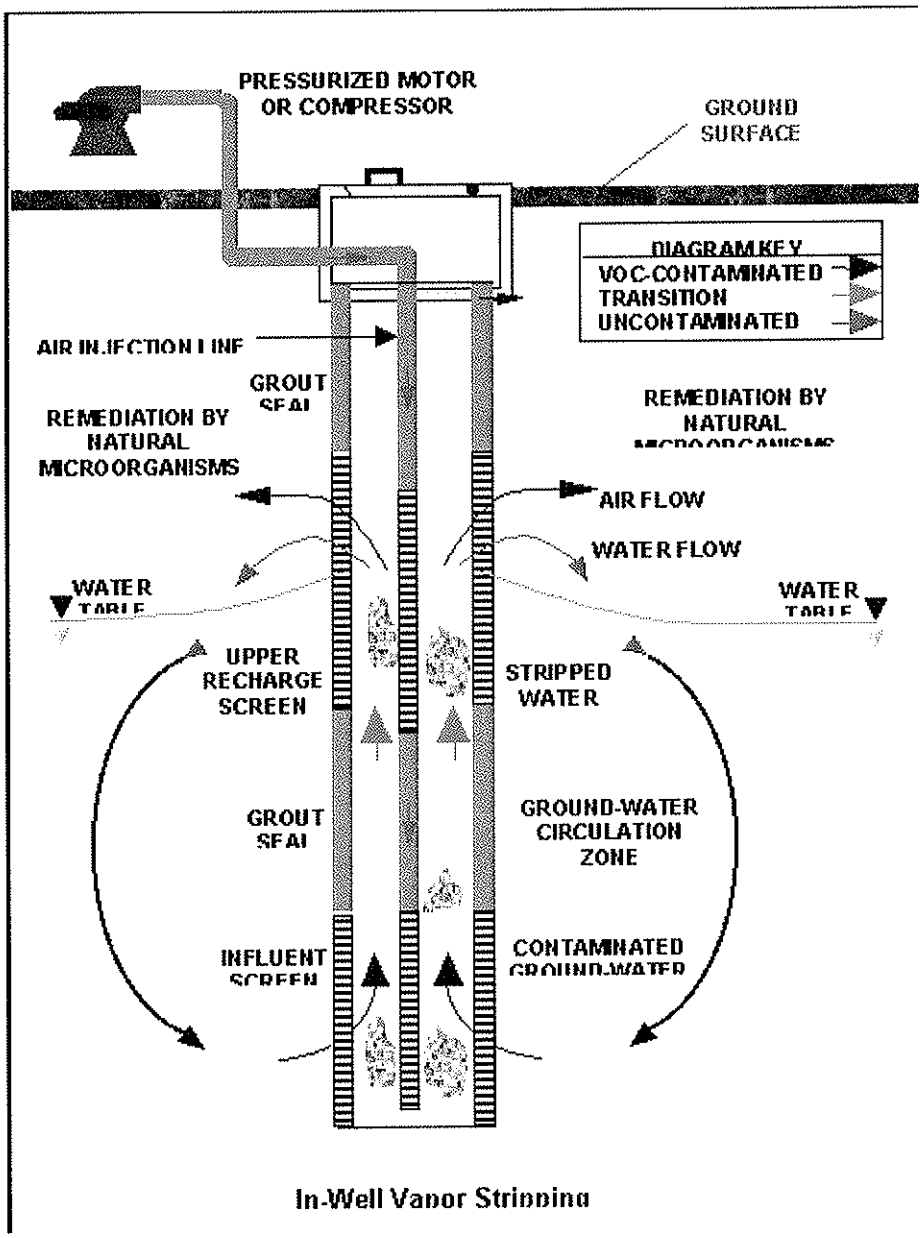

Injection Well
Steam-Stripped Water
Hot Water Reinjection
Low-Quality Steam
Production Well
Oil and Water Production
Absorption Layer
Hot Water Displacement
Residual Oil Saturation
Original Oil Accumulation
Oil Bank
Hot Water Formation
Steam Injection


Water
Curling
Jet
Sand
Slurry
Notch

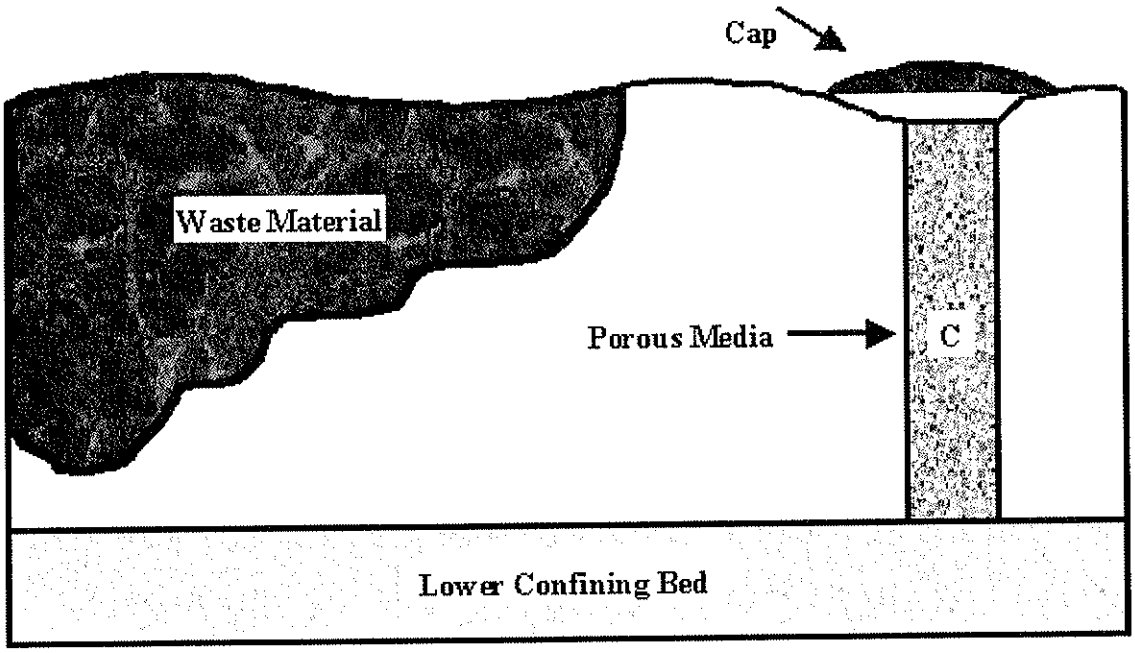

Activated Carbon Filter
Blower
Ambient Air
Off Air
Monitoring Wells
Grout
Bentonite Seal
Unsaturated Zone
Working GW Level
Resting GW Level
Capillary Zone
Stripping Zone
Artificial Pack
Screen
Bentonite Seal
GW Circulation
GW Circulation
Saturated Zone

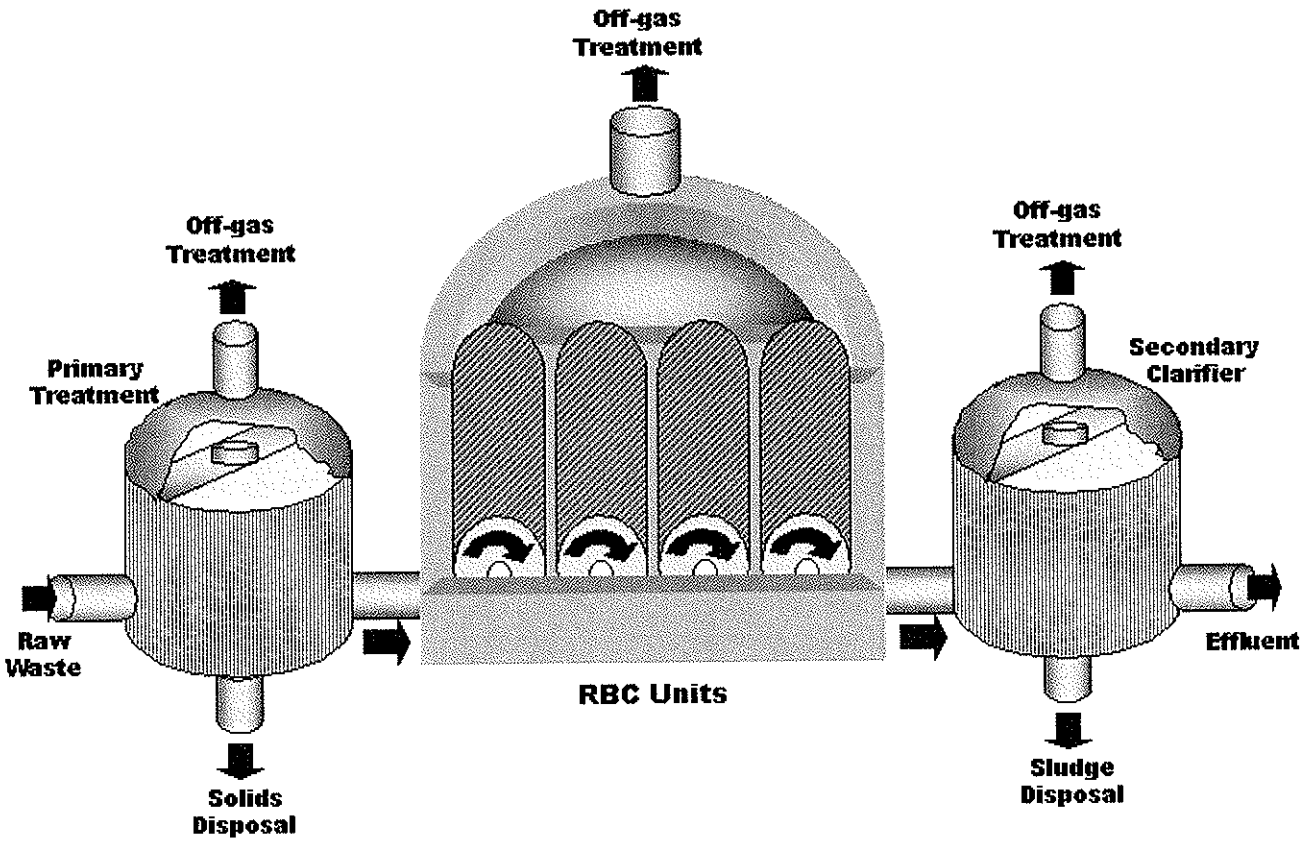


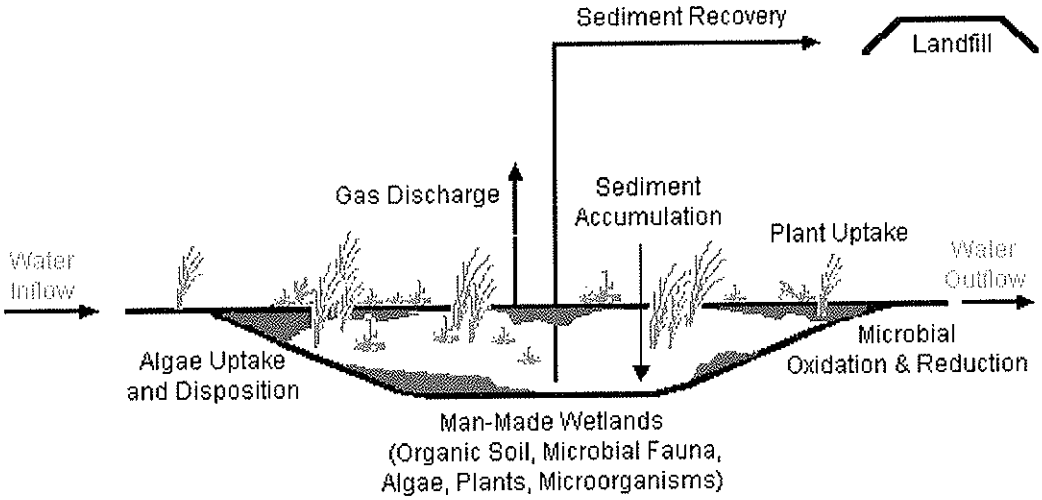
In-Well Vapor Stripping

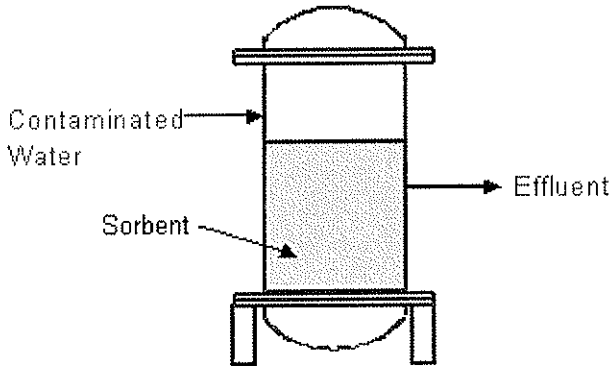


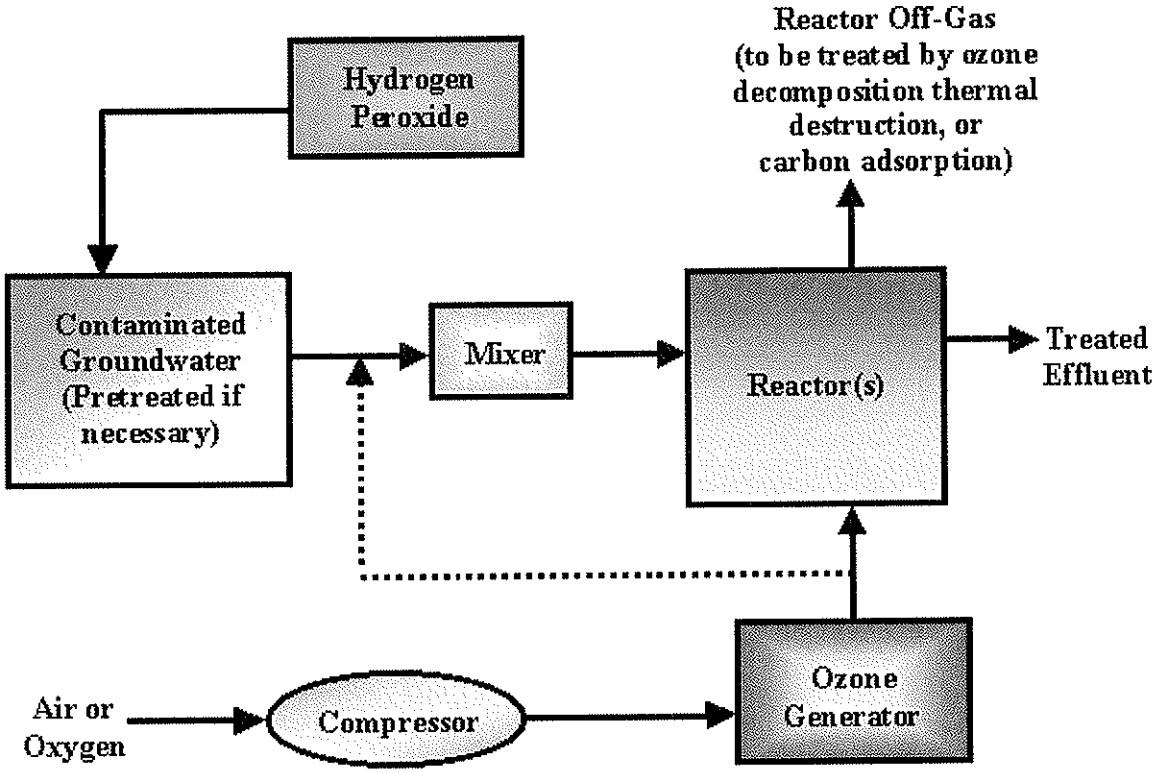
In-Well Vapor Stripping

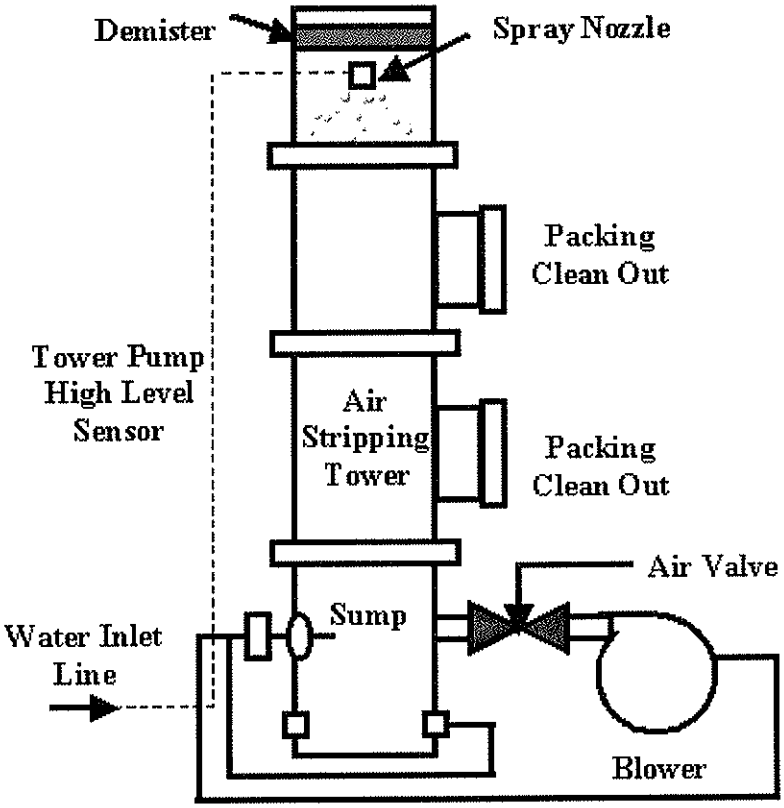

Cap
Waste Material
Porous Media
C
Lower Confining Bed

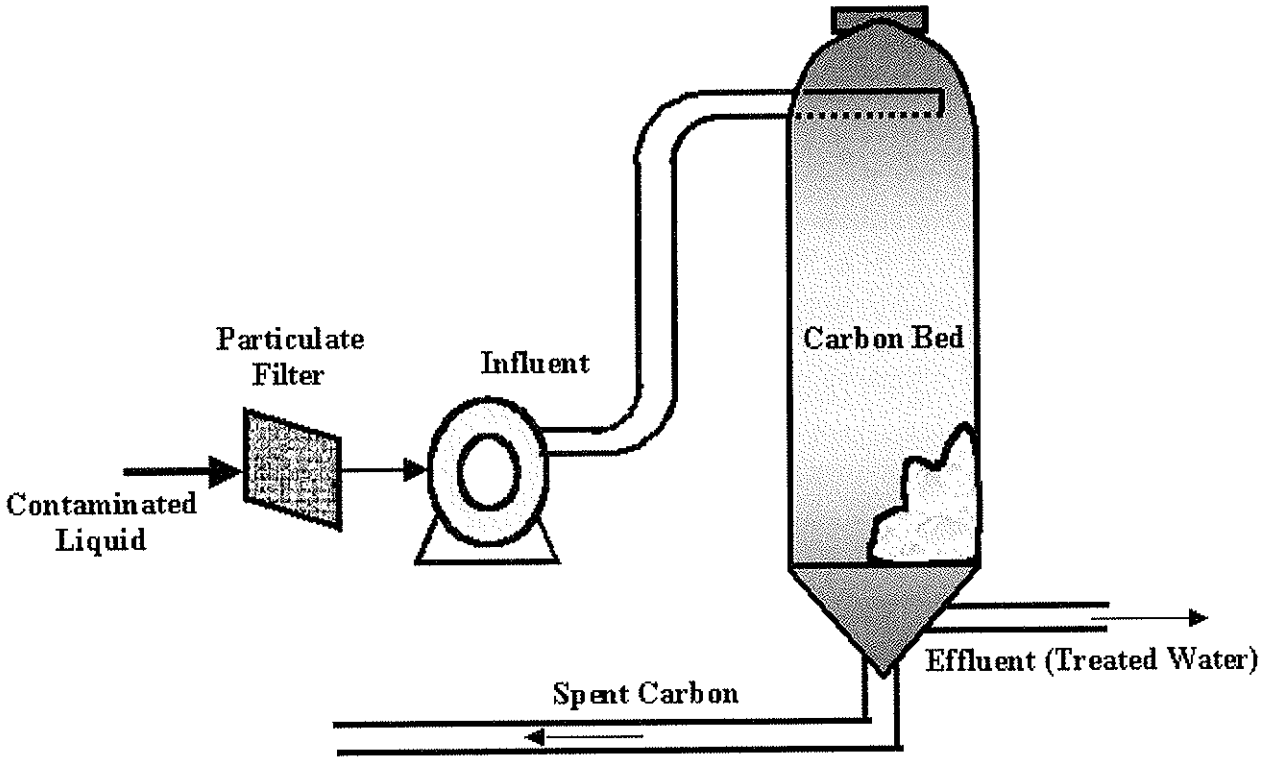

Off-gas Treatment
Off-gas Treatment
Primary Treatment
Raw Waste
Solids Disposal
RBC Units
Off-gas Treatment
Secondary Clarifier
Effluent
Sludge Disposal

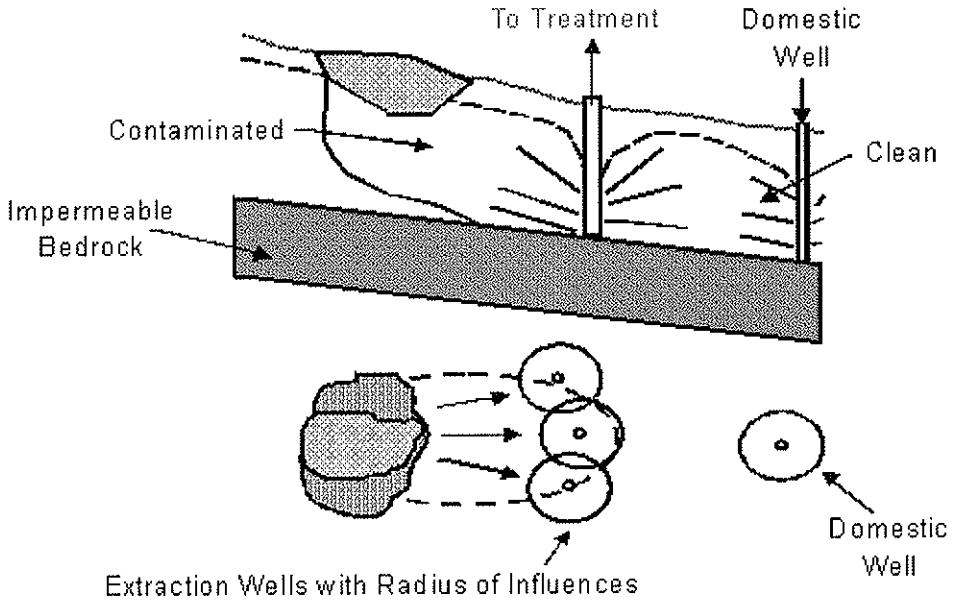

Sediment Recovery
Landfill
Gas Discharge
Sediment
Accumulation
Plant Uptake
Water
Inflow
Water
Outflow
Algae Uptake
and Disposition
Microbial
Oxidation & Reduction
Man-Made Wetlands
(Organic Soil, Microbial Fauna,
Algae, Plants, Microorganisms)

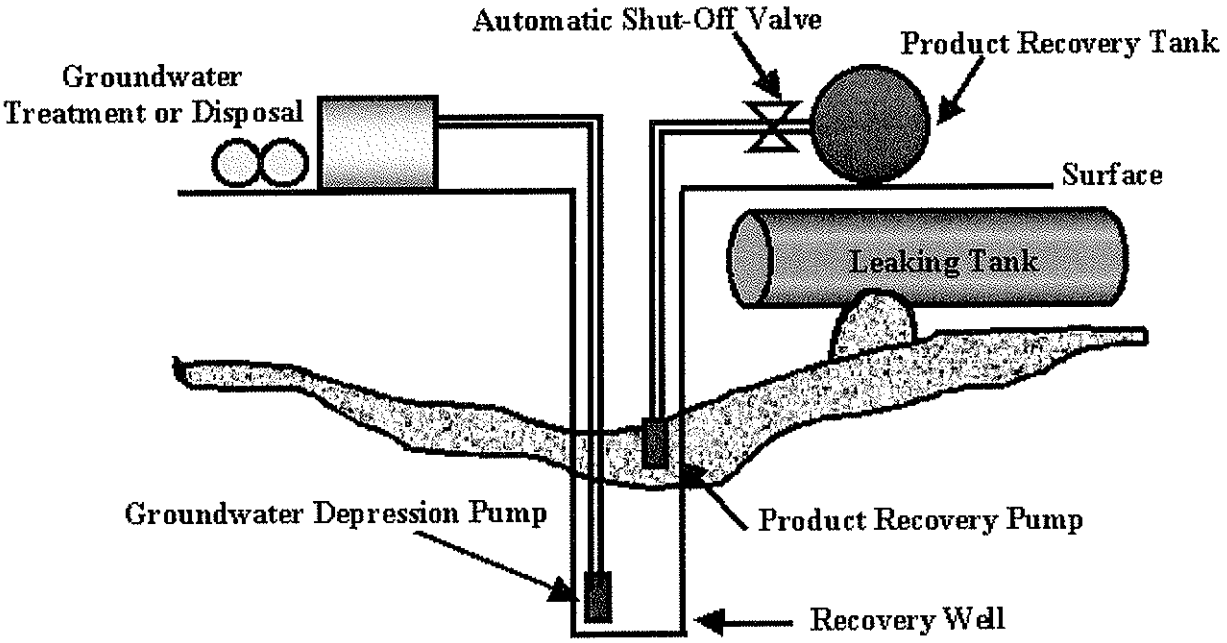

Contaminated
Water
Sorbent
Effluent

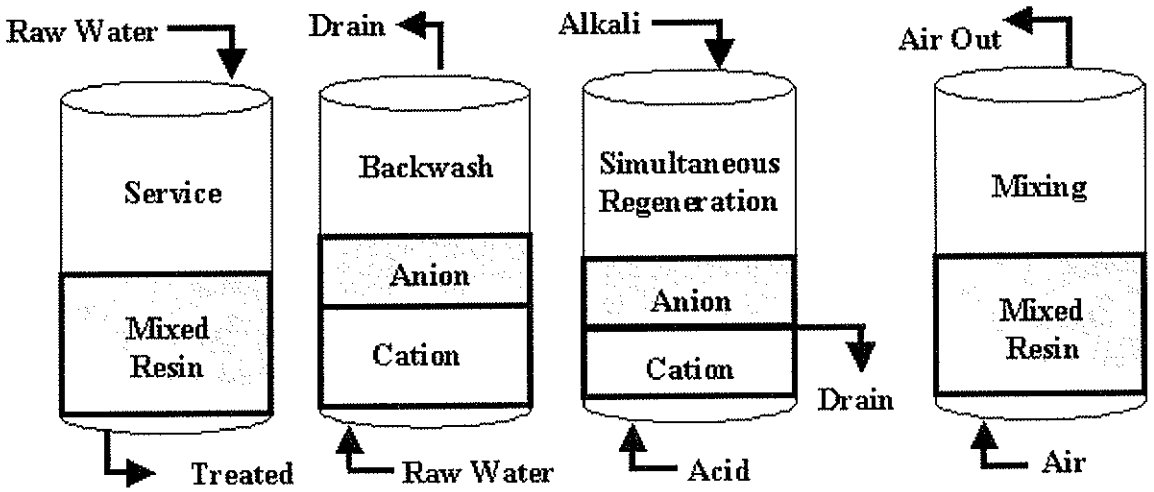

Reactor Off-Gas
(to be treated by ozone decomposition thermal destruction, or carbon adsorption)
Hydrogen Peroxide
Contaminated Groundwater (Pretreated if necessary)
Mixer
Reactor(s)
Treated Effluent
Air or Oxygen
Compressor
Ozone Generator


Demister
Spray Nozzle
Packing
Clean Out
Tower Pump
High Level
Sensor
Air
Stripping
Tower
Packing
Clean Out
Air Valve
Sump
Water Inlet
Line
Blower


Particulate
Filter
Influent
Carbon Bed
Contaminated
Liquid
Effluent (Treated Water)
Spent Carbon

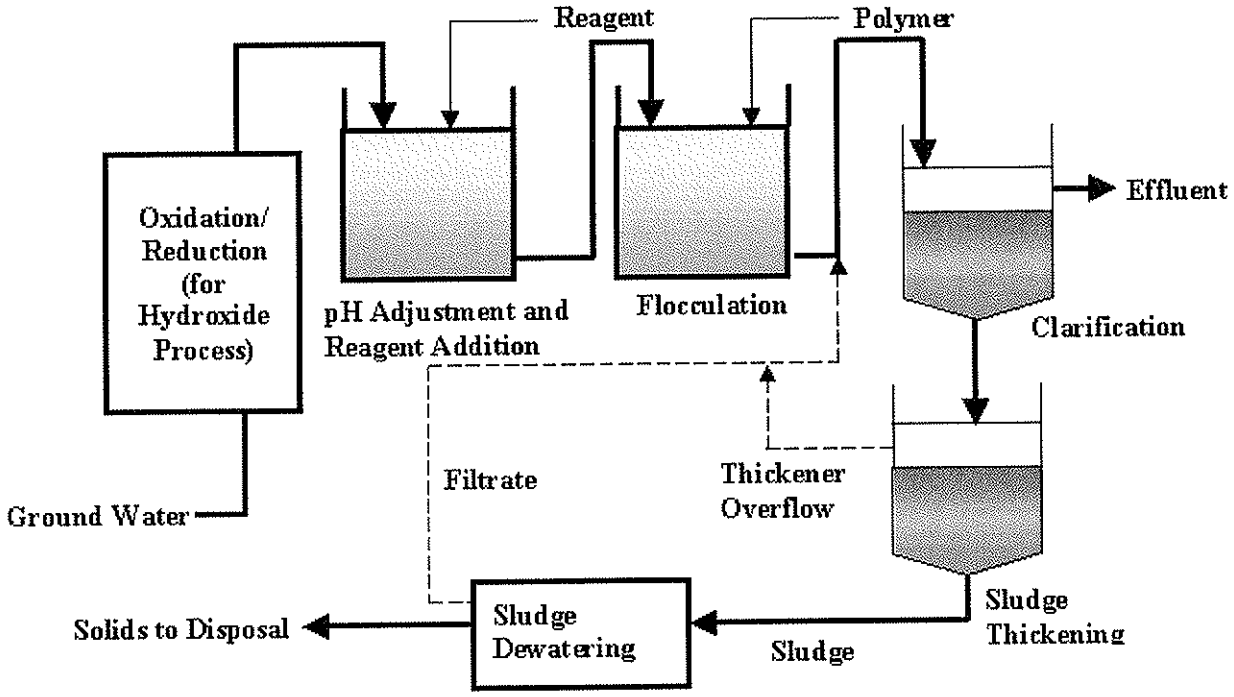

To Treatment
Domestic Well
Contaminated
Clean
Impermeable Bedrock
Domestic Well
Extraction Wells with Radius of Influences

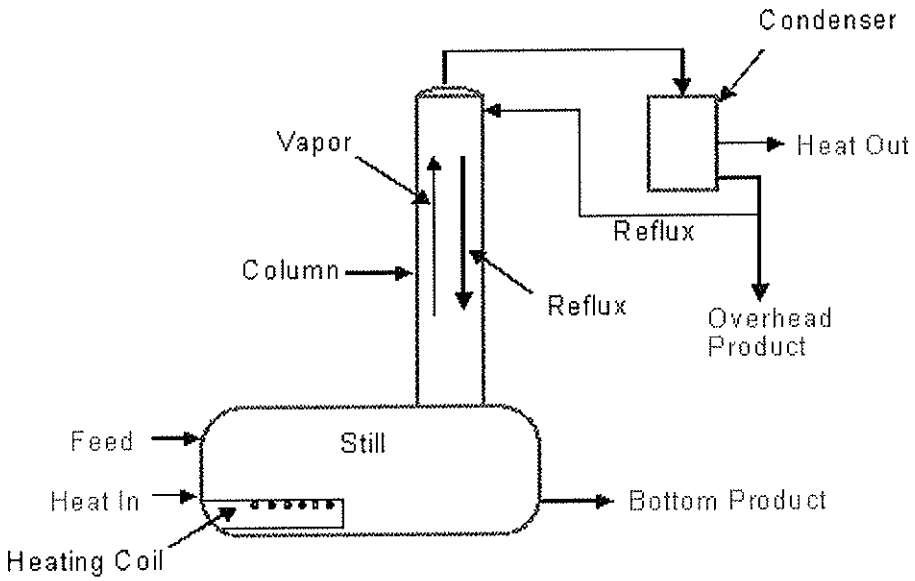

Automatic Shut-Off Valve
Product Recovery Tank
Groundwater
Treatment or Disposal
Surface
Leaking Tank
Groundwater Depression Pump
Product Recovery Pump
Recovery Well

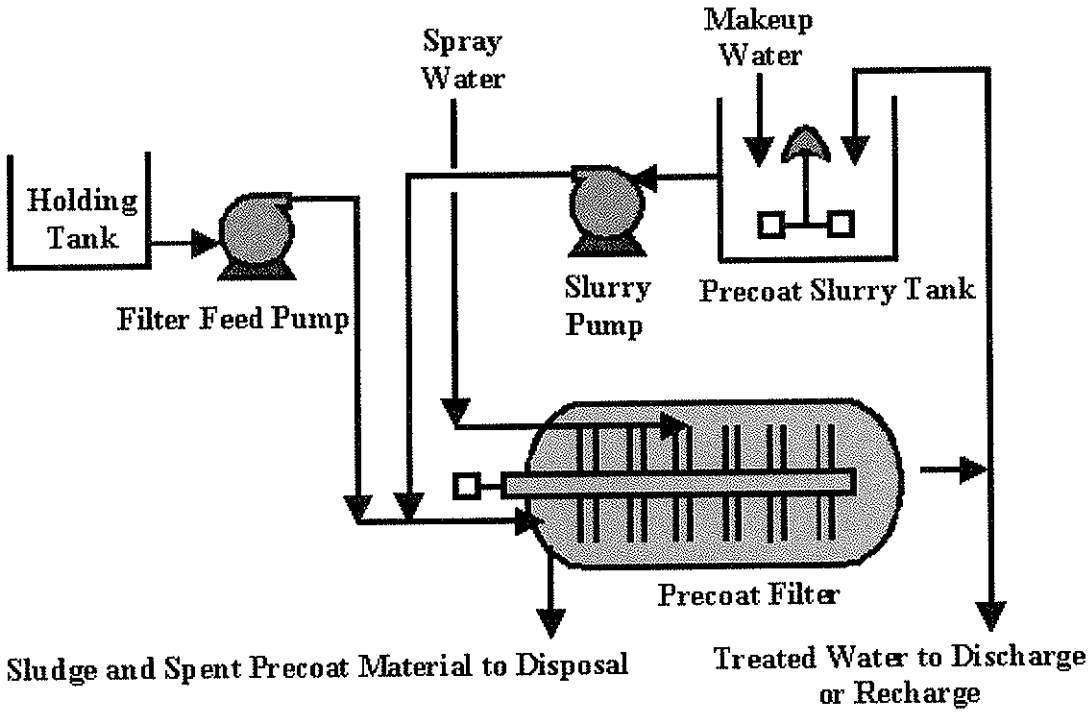


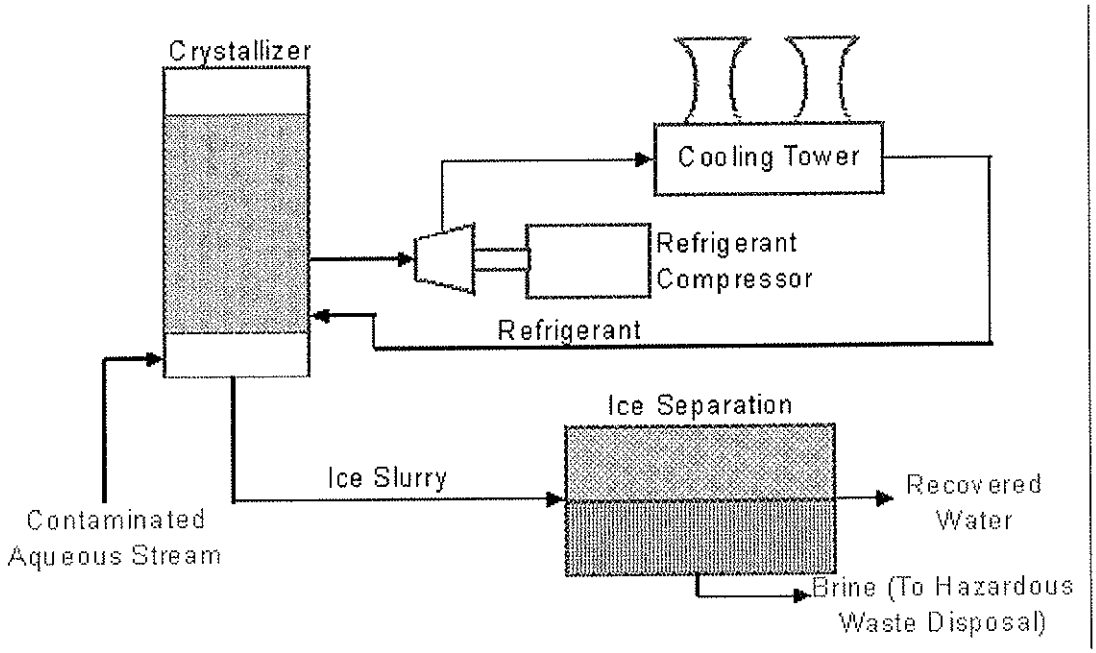
Principle of mixed-bed ion exchange: (a) Service period; (b) Backwash period (c) Simultaneous Regeneration

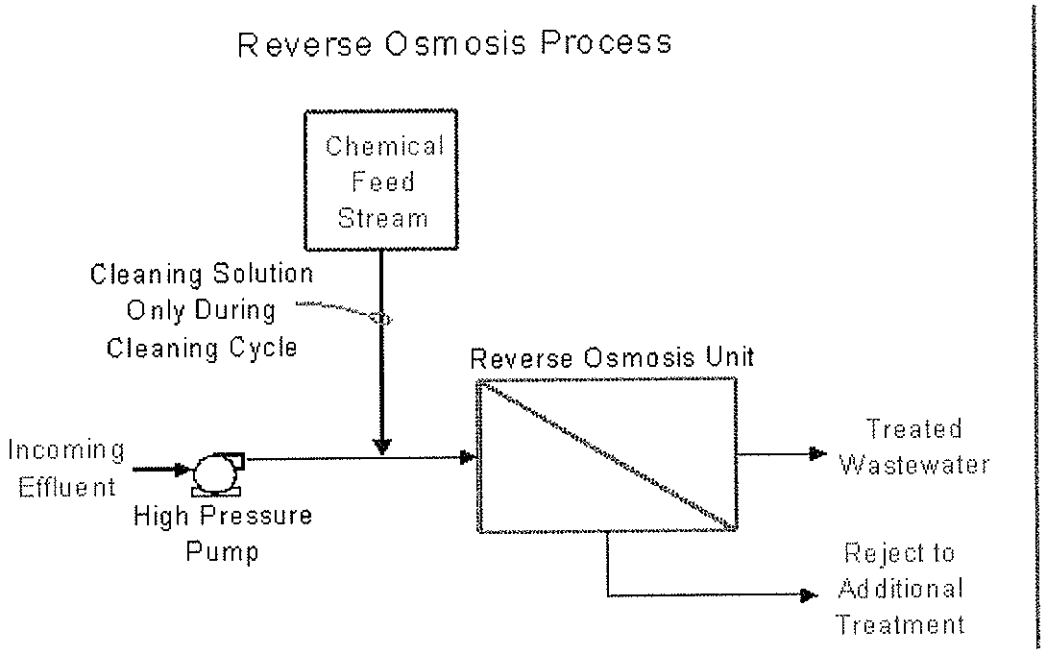
Source: Chemical Engineer's Handbook, Perry and Chilton (5th Edition)

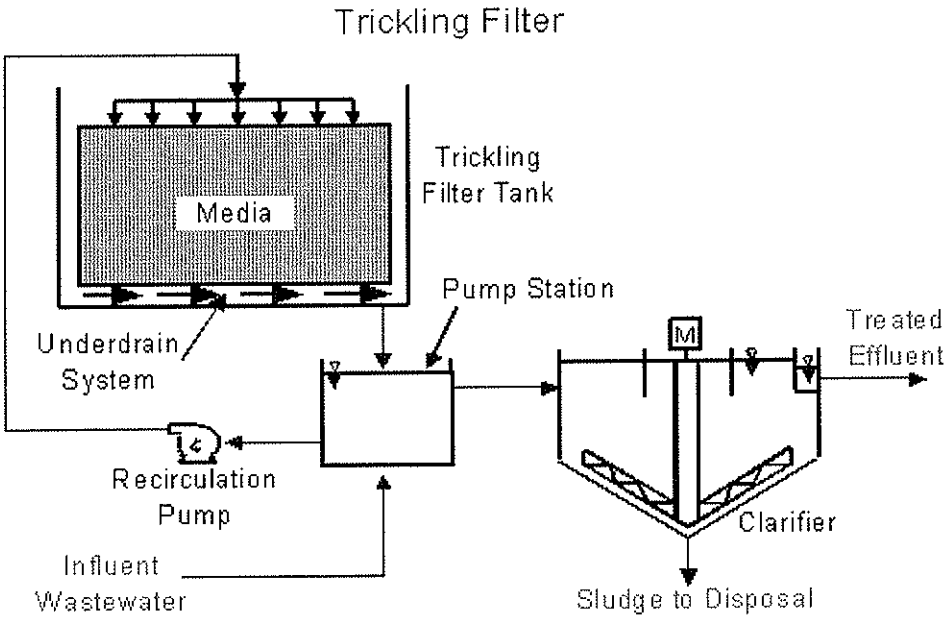

Reagent
Polymer
Oxidation/
Reduction
(for
Hydroxide
Process)
Effluent
pH Adjustment and
Reagent Addition
Flocculation
Clarification
Filtrate
Thickener
Overflow
Ground Water
Sludge
Thickening
Solids to Disposal
Sludge
Dewatering
Sludge

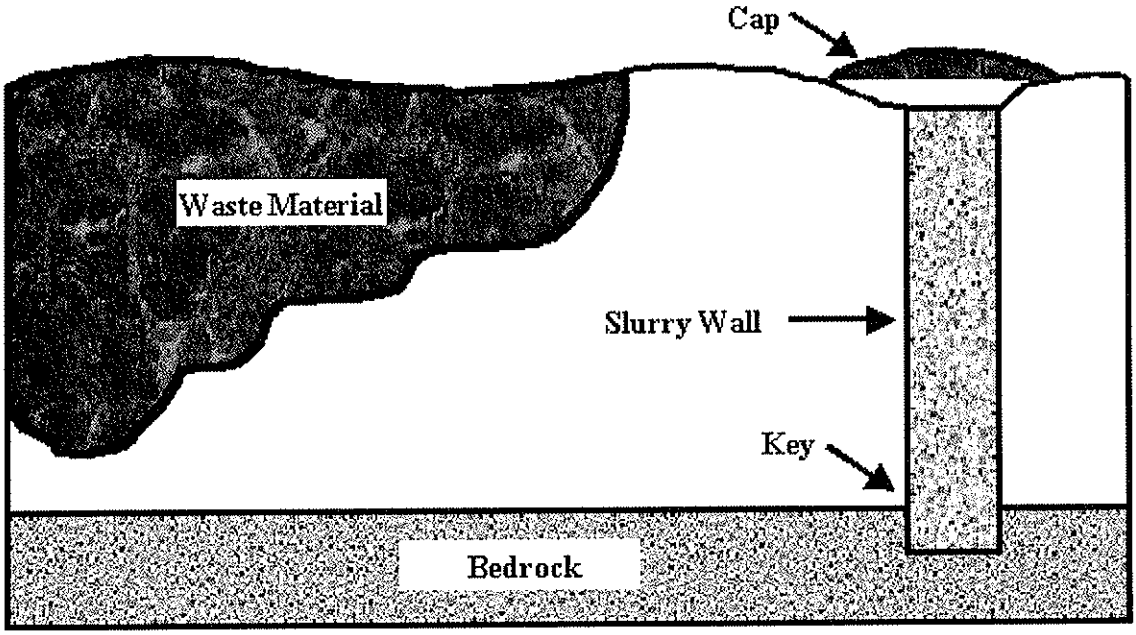

Condenser
Vapor
Heat Out
Reflux
Column
Reflux
Overhead
Product
Feed
Still
Heat In
Bottom Product
Heating Coil

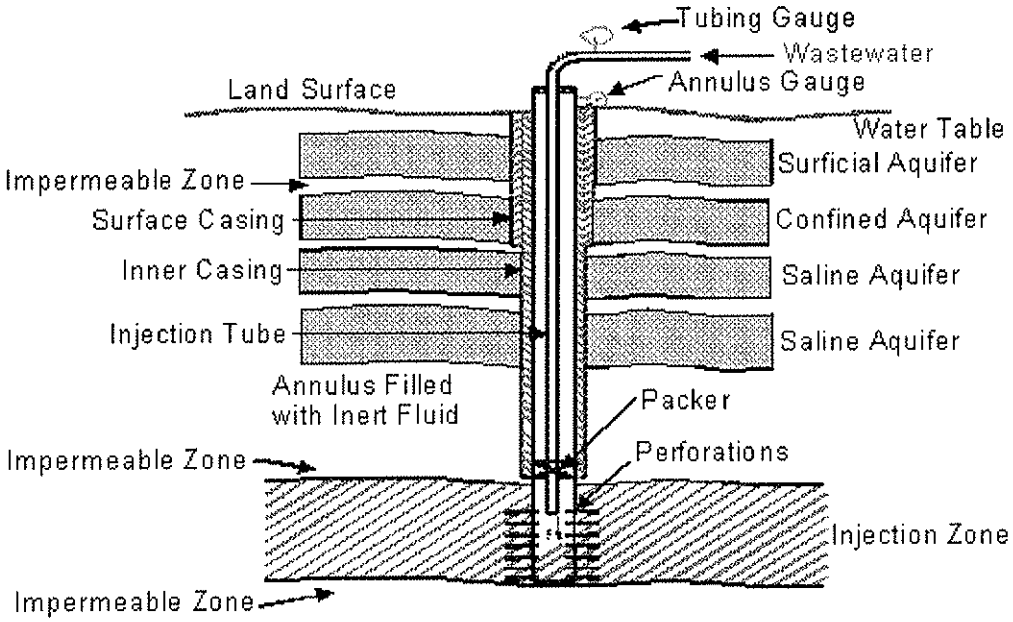

Spray
Water
Makeup
Water
Holding
Tank
Filter Feed Pump
Slurry
Pump
Precoat Slurry Tank
Precoat Filter
Sludge and Spent Precoat Material to Disposal
Treated Water to Discharge
or Recharge

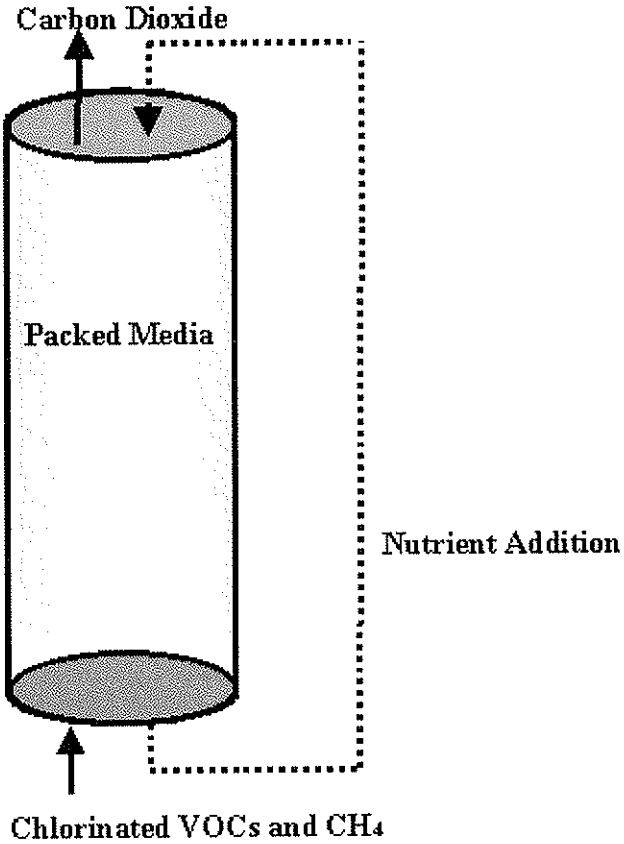

Crystallizer
Cooling Tower
Refrigerant
Compressor
Refrigerant
Ice Separation
Ice Slurry
Recovered
Water
Contaminated
Aqueous Stream
Brine (To Hazardous
Waste Disposal)

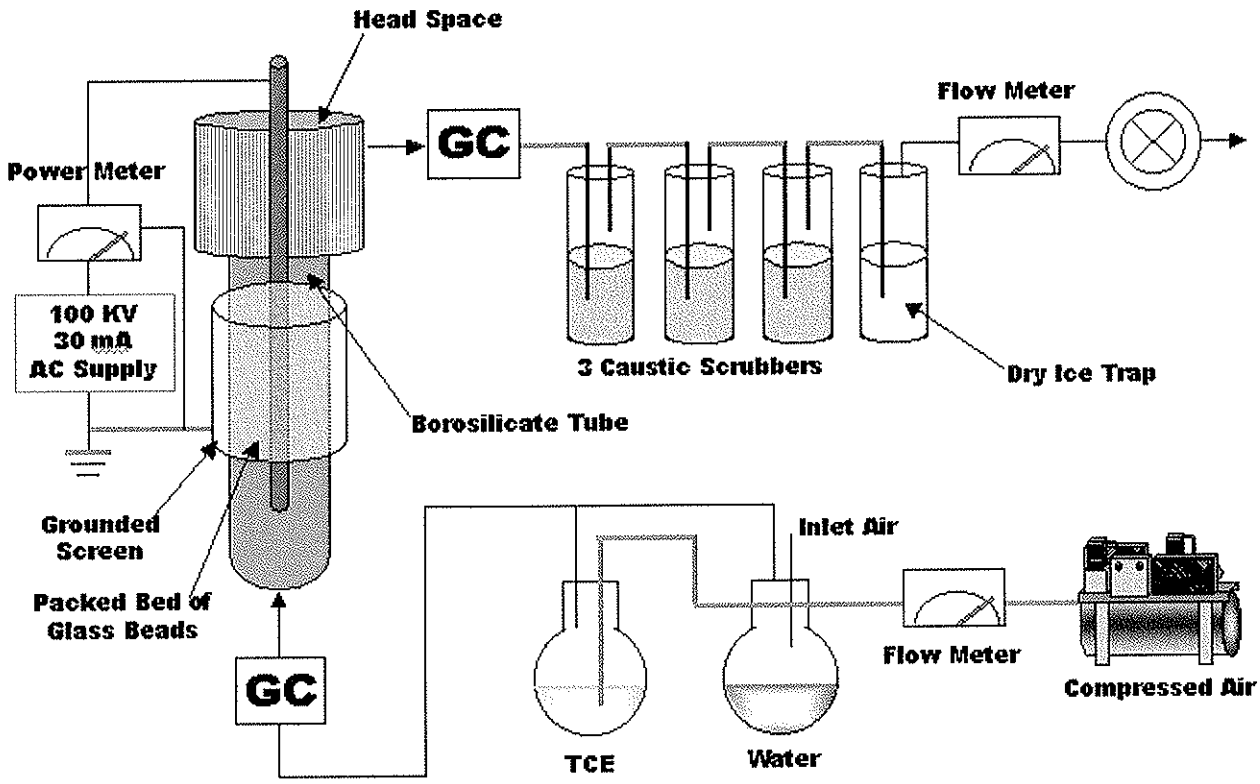

Reverse Osmosis Process
Chemical Feed Stream
Cleaning Solution Only During Cleaning Cycle
Reverse Osmosis Unit
Incoming Effluent
High Pressure Pump
Treated Wastewater
Reject to Additional Treatment

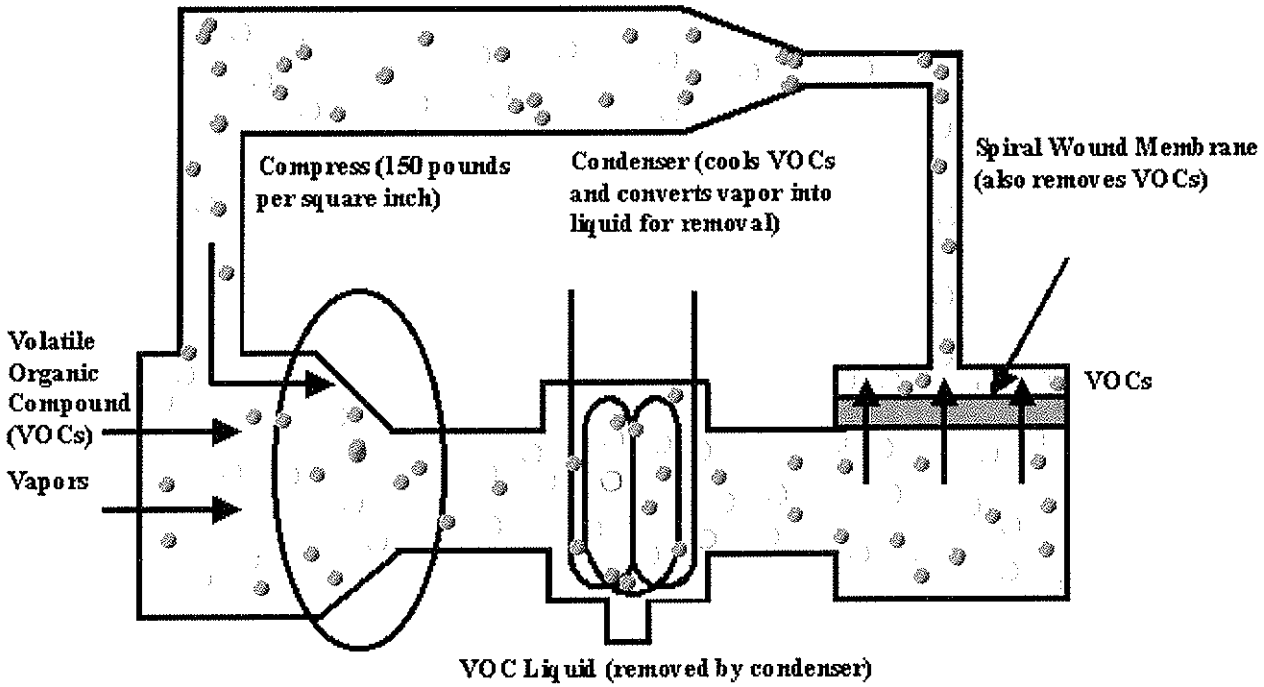

Trickling Filter
Media
Trickling
Filter Tank
Pump Station
Underdrain
System
Treated
Effluent
M
Recirculation
Pump
Clarifier
Influent
Wastewater
Sludge to Disposal

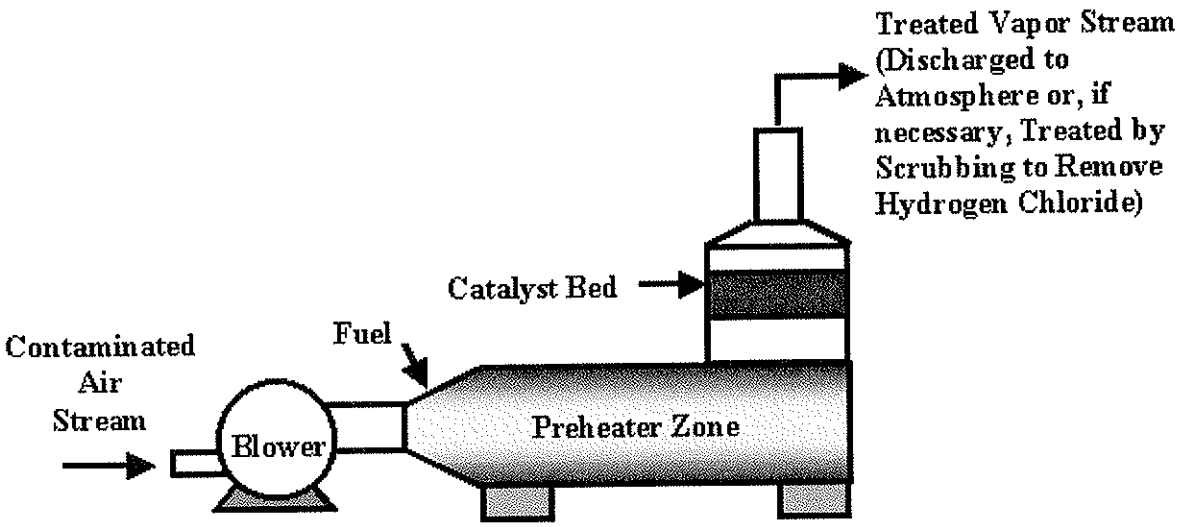

Cap
Waste Material
Slurry Wall
Key
Bedrock

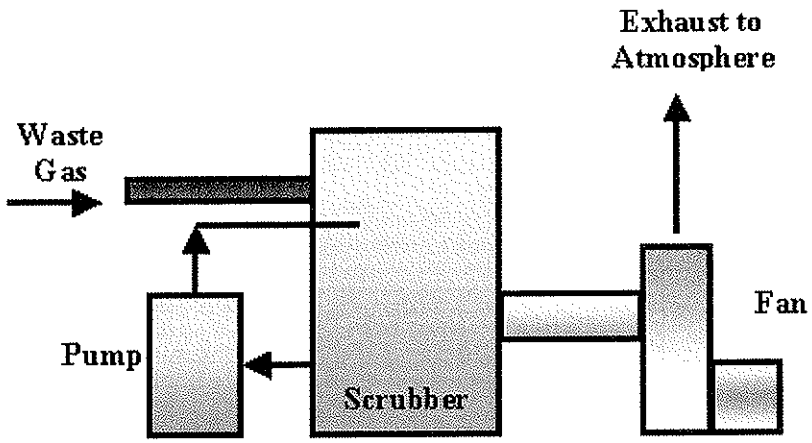

Tubing Gauge
Wastewater
Annulus Gauge
Land Surface
Water Table
Surficial Aquifer
Impermeable Zone
Surface Casing
Confined Aquifer
Inner Casing
Saline Aquifer
Injection Tube
Saline Aquifer
Annulus Filled
with Inert Fluid
Packer
Impermeable Zone
Perforations
Injection Zone
Impermeable Zone


Carbon Dioxide
Packed Media
Nutrient Addition
Chlorinated VOCs and CH4


Head Space
GC
Flow Meter
Power Meter
100 KV
30 mA
AC Supply
3 Caustic Scrubbers
Dry Ice Trap
Borosilicate Tube
Grounded
Screen
Packed Bed of
Glass Beads
GC
Inlet Air
Flow Meter
Compressed Air
TCE
Water


Compress (150 pounds per square inch)
Condenser (cools VOCs and converts vapor into liquid for removal)
Spiral Wound Membrane (also removes VOCs)
Volatile Organic Compound (VOCs)
Vapors
VOCs
VOC Liquid (removed by condenser)


Treated Vapor Stream (Discharged to Atmosphere or, if necessary, Treated by Scrubbing to Remove Hydrogen Chloride)
Catalyst Bed
Fuel
Contaminated Air Stream
Blower
Preheater Zone



Scrubbing the Gas

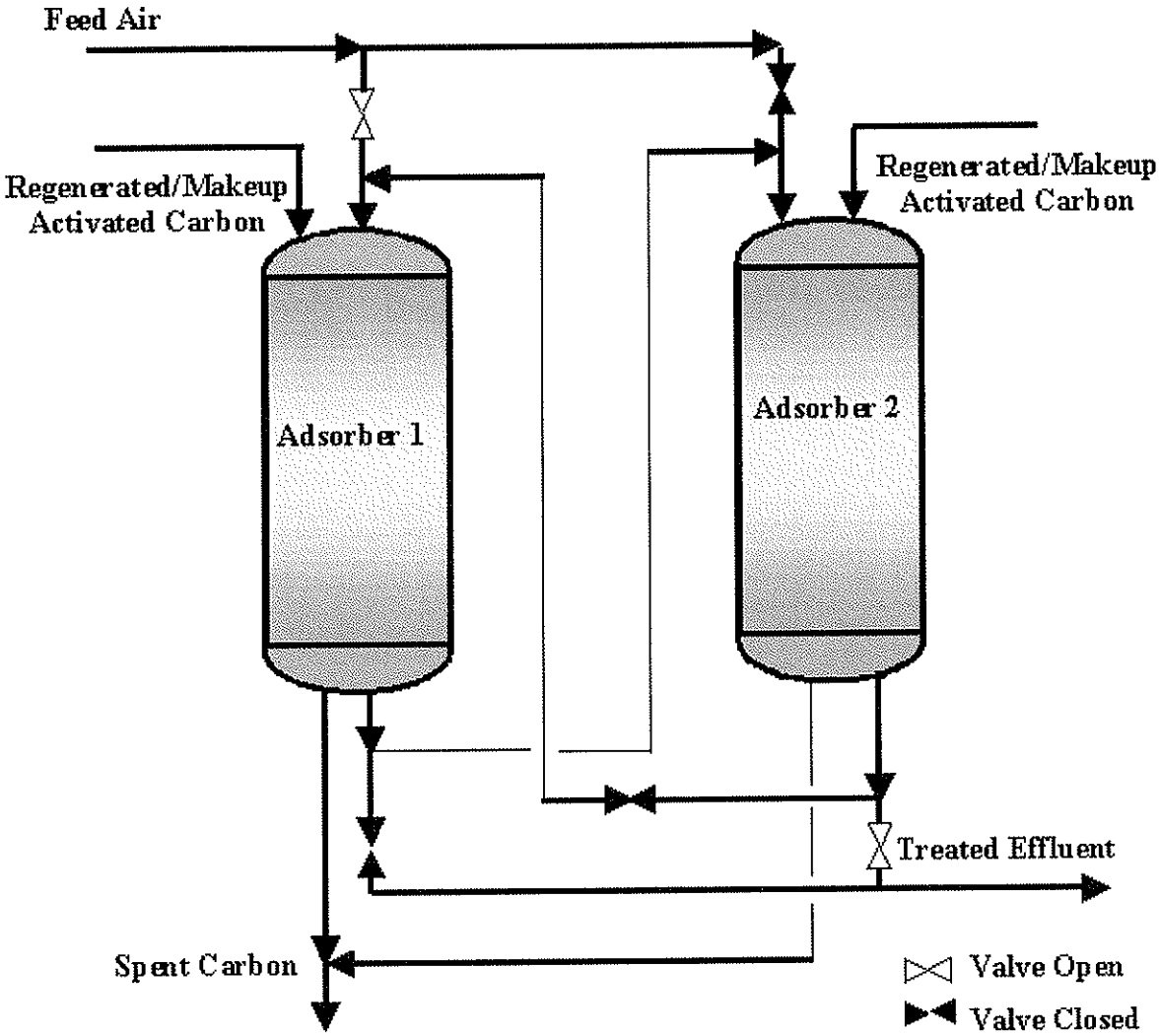

Feed Air
Regenerated/Makeup
Activated Carbon
Regenerated/Makeup
Activated Carbon
Adsorber 1
Adsorber 2
Treated Effluent
Spent Carbon
Valve Open
Valve Closed

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TABLE 2-1 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF NONHALOGENATED 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.

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

	Technology (Section & Title)	Development Status	Use Rating	Applicability*	Reliability*	Cleanup Time*	Technology Function*

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TABLE 2-2 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF HALOGENATED 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.

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	Technology (Section & Title)	Development Status	Use Rating	Applicability*	Reliability*	Cleanup Time*	Technology Function*

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TABLE 2-3 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF NONHALOGENATED SEMIVOLATILE 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.

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

	Technology (Section & Title)	Development Status	Use Rating	Applicability*	Reliability*	Cleanup Time*	Technology Function*

TABLE 2-3 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF NONHALOGENATED SEMIVOLATILE ORGANIC COMPOUNDS

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

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

	Technology (Section & Title)	Development Status	Use Rating	Applicability*	Reliability*	Cleanup Time*	Techn Func
SOIL, SEDIMENT, BEDROCK AND SLUDGE section of this table now begins:							
3.1 IN SITU BIOLOGICAL TREATMENT technologies now listed:							
	Bioventing	Full	Limited	Refer to profile	Refer to profile	Refer to profile	Dest
	Enhanced Biodegradation	Full	Wide	Refer to profile	Refer to profile	Refer to profile	Dest
	Phytoremediation	Pilot	Wide	Average	Average	Worse	Dest
3.2 IN SITU PHYSICAL/CHEMICAL TREATMENT technologies now listed:							
	Chemical Oxidation	Full	Limited	Refer to Profile	Average	Better	Dest
	Electrokinetic Separation	Full	Limited	Average	Average	Average	Ext
	Fracturing	Full	Limited	Refer to profile	Refer to profile	Refer to profile	Ext
	Soil Flushing	Pilot	Limited	Average	Average	Worse	Ext
	Soil Vapor Extraction	Full	Limited	Average	Better	Average	Ext
	Solidification /Stabilization	Full	Limited	Better	Better	Better	Imn
3.3 IN SITU THERMAL TREATMENT technologies now listed:							
	Thermal Treatment	Full	Limited	Better	Better	Better	Ext
3.4 EX SITU BIOLOGICAL TREATMENT (ASSUMING EXCAVATION) technologies now listed:							
	Biopiles	Full	Wide	Average	Better	Average	Dest
	Compositing	Full	Wide	Average	Better	Average	Dest
	Land Farming	Full	Wide	Better	Better	Worse	Dest
	Slurry Phase Bio. Treatment	Full	Limited	Better	Average	Average	Dest
3.5 EX SITU PHYSICAL/CHEMICAL TREATMENT (ASSUMING EXCAVATION) technologies nc listed:							
	Chemical Extraction	Full	Limited	Better	Average	Average	Extract/I
	Chemical Reduction /Oxidation	Full	Limited	Average	Better	Better	Dest
	Dehalogenation	Full	Limited	Worse	NA	NA	Dest
	Separation	Full	Limited	Average	Better	Better	Ext
	Soil Washing	Full	Limited	Average	Better	Better	Ext

	Solidification /Stabilization	Full	Limited	Better	Better	Better	Imn
3.6 EX SITU THERMAL TREATMENT (ASSUMING EXCAVATION) technologies now listed:							
	Hot Gas Decontamination	Full	Limited	Worse	Better	Better	Dest
	Incineration	Full	Wide	Better	Average	Better	Dest
	OB/OD	Full	Limited	Worse	Better	Better	Dest
	Pyrolysis	Full	Limited	Better	Worse	Better	Dest
	Thermal Desorption	Full	Wide	Better	Average	Better	Ext
3.7 CONTAINMENT							
	Landfill Cap	Full	Refer to Profile	Refer to Profile	Refer to Profile	Refer to Profile	Refer to
	Landfill Cap Enhancements	Pilot	Refer to Profile	Refer to Profile	Refer to Profile	Refer to Profile	Refer to
3.8 OTHER TREATMENT technologies now listed:							
	Excavation and Off-Site Disp.	NA	Wide	Average	Better	Better	Extract/
GROUND WATER, SURFACE WATER AND LEACHATE section of this table now begins:							
3.9 IN SITU BIOLOGICAL TREATMENT technologies now listed:							
	Enhanced Biodegradation	Full	Limited	Refer to profile	Refer to profile	Refer to profile	Dest
	Natural Attenuation	Full	Wide	Refer to profile	Refer to profile	Refer to profile	Dest
	Phytoremediation	Full	Limited	Average	Average	Worse	Extract/
3.10 IN SITU PHYSICAL/CHEMICAL TREATMENT technologies now listed:							
	Air Sparging	Full	Limited	Average	Average	Better	Ext
	Bioslurping	Full	Limited	Average	Better	Average	Dest
	Chemical Oxidation	Full	Limited	Average	Worse	Better	Dest
	Directional Wells (enhancement)	Full	Limited	Refer to Profile	Refer to Profile	Refer to Profile	Extract/I
	Dual Phase Extraction	Full	Limited	Better	Better	Average	Ext
	Thermal Treatment	Full	Limited	Better	Better	Better	Ext
	Hydrofracturing Enhancements	Full	Limited	Refer to Profile	Refer to Profile	Refer to Profile	Refer to
	In-Well Air Stripping	Full	Limited	Average	Average	Worse	Ext
	Passive/Reactive Treatment Walls	Full	Limited	Better	Better	Worse	Dest
3.11 EX SITU BIOLOGICAL TREATMENT technologies now listed:							
	Bioreactors	Full	Limited	Better	Better	Average	Dest
	Constructed Wetlands	Full	Limited	Average	Average	NA	Immob. /

3.12 EX SITU PHYSICAL/CHEMICAL TREATMENT technologies now listed:							
	Adsorption/ Absorption	Full	Limited	Average	Average	Worse	Ext
	Advanced Oxidation Processes	Full	Limited	Better	Better	Worse	Dest
	Air Stripping	Full	Wide	Better	Worse	Worse	Ext
	Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption	Full	Wide	Better	Better	Worse	Ext
	Ground Water Pumping	Full	Limited	Average	Average	Worse	Ext
	Ion Exchange	Full	Limited	Worse	Worse	Worse	Ext
	Prec./Coag./Flocc.	Full	Limited	Worse	Worse	Worse	Ext
	Separation	Full	Limited	Better	Better	Better	Ext
	Sprinkler Irrigation	Full	Limited	Better	Worse	Worse	Ext
3.13 CONTAINMENT technologies now listed:							
	Physical Barriers	Full	Wide	Average	Better	Better	Imn
	Deep Well Injection	Full	Wide	Average	Average	NA	Imn

NA: Not Available

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TABLE 2-4 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF HALOGENATED SEMIVOLATILE 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.

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

	Technology (Section & Title)	Development Status	Use Rating	Applicability*	Reliability*	Cleanup Time*	Technology Function*

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

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.

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

	Technology (Section & Title)	Development Status	Use Rating	Applicability*	Reliability*	Cleanup Time*	Technology Function*

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TABLE 2-6 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.

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

	Technology (Section & Title)	Development Status	Use Rating	Applicability*	Reliability*	Cleanup Time*	Technology Function*

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TABLE 2-7 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF RADIONUCLIDES

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.

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

	Technology (Section & Title)	Development Status	Use Rating	Applicability*	Reliability*	Cleanup Time*	Technology Function*

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TABLE 2-8 TREATMENT TECHNOLOGIES SCREENING MATRIX: TREATMENT OF EXPLOSIVES

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.

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

	Technology (Section & Title)	Development Status	Use Rating	Applicability*	Reliability*	Cleanup Time*	Technology Function*

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Section 3 Treatment Perspectives

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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 chemical 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 ground water 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.

These concepts about site remediation strategies and representative technologies associated with them are summarized in Figure1: Classification of Remedial Technologies by Function. 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 ground water pumping and air stripping to simultaneously remove contaminants from both ground water 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 14 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).
  - Containment.
  - Other treatment processes.
- Ground water, 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).
  - Containment.
- Air emissions/off-gas treatment.

These 14 treatment groups correspond to the following 14 subsections (3.1 through 3.14). The discussion of the broad application of each treatment group (e.g., in situ biological treatment for soil, sediment, bedrock 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 *Treatment Technologies for Site Cleanup: Annual Status Report Tenth Edition (February 2001)*, 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).
- Developmental Status (full scale vs. pilot scale).
- Typical Treatment Train.
- Residuals Produced.
- O&M or Capital Intensive.
- Availability.
- Contaminants Treated.
- System Reliability/Maintainability.
- Cleanup Time.
- Overall Cost.

Additionally, a brief description of each treatment technology is presented at the beginning of each process description.

TABLE 3-1a. DEFINITION OF LEGENDS USED IN THE TREATMENT TECHNOLOGIES SCREENING MATRIX

Factors	Definitions			
Development Status Scale status of an available technology.	**F** Full scale: technology has been used in real site remediation.		**P** Pilot Scale: studies conducted in the field or the laboratory to fine-tune the design of the technology.	
Treatment Train Is the technology only effective as part of the treatment train?	**Y** Technology must be used with the combination of other technologies as a treatment train.		**N** Technology can be used as a stand alone one.	
Residuals Produced Residuals need to be treated.	**S** Solid	**L** Liquid	**V** Vapor	**N** None

O&M or Capital Intensive Main cost intensive parts.	**O&M** Operation and Maintenance Intensive	**Cap** Capital Intensive	**B** Both O&M and Capital Intensive	**N** Neither O&M or Capital Intensive

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

Factors and Definitions	Worse △	Average ○	Better ▩	Other ◈
Availability Number of vendors that can design, construct, and maintain the technology.	Fewer than 2 vendors	2-4 vendors	More than 4 vendors	Data Not Available
Contaminants Treated Contaminants are classified into the following eight groups: - Nonhalogenated VOCs; - Halogenated VOCs; - Nonhalogenated SVOCs; - Halogenated SVOCs; - Fuels; - Inorganics; - Radionuclides; - Explosives.	No Demonstrated Effectiveness at Pilot or Full Scale	Limited Effectiveness Demonstrated at Pilot or Full Scale	Effectiveness Demonstrated at Pilot or Full Scale	Level of Effectiveness highly dependent upon specific contaminant and its application/design
System Reliability /Maintainability The expected range of demonstrated reliability and maintenance relative to other effective technologies	Low reliability and high maintenance	Average reliability and average maintenance	High reliability and low maintenance	Not applicable
Cleanup Time provided that this technology is effective for this specific contaminant. 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 ground water.	More than 3 years for in situ soil	1-3 years	Less than 1 year	Contaminant specific
	More than 1 year for ex situ soil	0.5-1 year	Less than 0.5 year	Contaminant specific
	More than 10 years for water	3-10 years	Less than 3 years	Contaminant specific
Overall Cost Design, construction, and operations and maintenance (O&M) costs of the core process that defines each technology, exclusive of mobilization,	More than $330/metric ton ($300/ton) for soils	$110-$330 /metric ton ($100-$300 /ton)	Less than $110/metric ton ($100/ton)	Contaminant specific
	More than	$0.79-	Less than	Contaminant

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 ground water technologies, it is assumed that pumping costs average $0.07/1,000 liters ($0.25/1,000 gallons).	$2.64/1,000 liters ($10/1,000 gal.) for ground water	$2.64 /1,000 liters ($3.00-$10.00/ 1,000 gallons)	$0.79/1,000 liters ($3.00/1,000 gallons)	specific
	More than $11.33/kg ($25/lb) for air emissions and off-gases	$3.17-$11.33 /kg ($7-$25/lb)	Less than $3.17/kg ($7/lb)	Contaminant specific

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

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Remediation Technologies Screening Matrix and Reference Guide, Version 4.0

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- Ex situ thermal treatment (assuming excavation).
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- Other treatment processes.

- Ground water, surface water, and leachate:
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Residuals Produced Residuals need to be treated.	**S** Solid	**L** Liquid	**V** Vapor	**N** None

O&M or Capital Intensive Main cost intensive parts.	**O&M** Operation and Maintenance Intensive	**Cap** Capital Intensive	**B** Both O&M and Capital Intensive	**N** Neither O&M or Capital Intensive

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

Factors and Definitions	Worse △	Average ○	Better ■	Other ◆
Availability Number of vendors that can design, construct, and maintain the technology.	Fewer than 2 vendors	2-4 vendors	More than 4 vendors	Data Not Available
Contaminants Treated Contaminants are classified into the following eight groups: - Nonhalogenated VOCs; - Halogenated VOCs; - Nonhalogenated SVOCs; - Halogenated SVOCs; - Fuels; - Inorganics; - Radionuclides; - Explosives.	No Demonstrated Effectiveness at Pilot or Full Scale	Limited Effectiveness Demonstrated at Pilot or Full Scale	Effectiveness Demonstrated at Pilot or Full Scale	Level of Effectiveness highly dependent upon specific contaminant and its application/design
System Reliability /Maintainability The expected range of demonstrated reliability and maintenance relative to other effective technologies	Low reliability and high maintenance	Average reliability and average maintenance	High reliability and low maintenance	Not applicable
Cleanup Time provided that this technology is effective for this specific contaminant. 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 ground water.	More than 3 years for in situ soil	1-3 years	Less than 1 year	Contaminant specific
	More than 1 year for ex situ soil	0.5-1 year	Less than 0.5 year	Contaminant specific
	More than 10 years for water	3-10 years	Less than 3 years	Contaminant specific
Overall Cost Design, construction, and operations and maintenance (O&M) costs of the core process that defines each technology, exclusive of mobilization,	More than $330/metric ton ($300/ton) for soils	$110-$330 /metric ton ($100-$300 /ton)	Less than $110/metric ton ($100/ton)	Contaminant specific
	More than	$0.79-	Less than	Contaminant

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 ground water technologies, it is assumed that pumping costs average $0.07/1,000 liters ($0.25/1,000 gallons).	$2.64/1,000 liters ($10/1,000 gal.) for ground water	$2.64 /1,000 liters ($3.00-$10.00/ 1,000 gallons)	$0.79/1,000 liters ($3.00/1,000 gallons)	specific
	More than $11.33/kg ($25/lb) for air emissions and off-gases	$3.17-$11.33 /kg ($7-$25/lb)	Less than $3.17/kg ($7/lb)	Contaminant specific

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

TABLE 3-2: TREATMENT TECHNOLOGIES SCREENING MATRIX

Rating Codes
● Above Average
◑ Average
○ Below Average
N/A - "Not Applicable"
I/D - "Insufficient Data"
◇ - Level of Effectiveness highly dependent upon specific contaminant and its application

	Development Status	Treatment Train	Relative Overall Cost & Performance: O&M	Capital	System Reliability & Maintainability	Relative Costs	Time	Availability	Nonhalogenated VOC's	Halogenated VOC's	Nonhalogenated SVOC's	Halogenated SVOC's	Fuels	Inorganics	Radionuclides	Explosives
Soil, Sediment, Bedrock, and Sludge																
3.1 In Situ Biological Treatment																
4.1 Bioventing	●	●	●	●	●	●	◑	●	●	◇	●	○	●	○	◇	○
4.2 Enhanced Bioremediation	●	●	○	◑	●	●	◑	●	●	●	●	◇	●	◇	◇	●
4.3 Phytoremediation	●	●	●	●	○	●	○	◑	◑	◑	◑	◇	◑	◑	○	○
3.2 In Situ Physical/Chemical Treatment																
4.4 Chemical Oxidation	●	●	○	◑	◑	◑	●	●	◑	◑	○	◑	○	◇	○	◑
4.5 Electrokinetic Separation	●	○	○	◑	◑	○	◑	◑	◑	◑	◑	◑	○	●	◑	○
4.6 Fracturing	●	◑	◑	○	◑	◑	◑	●	◑	◑	◑	◑	◑	○	○	○
4.7 Soil Flushing	●	●	○	◑	◑	◑	◑	●	●	●	○	◑	◑	●	○	○
4.8 Soil Vapor Extraction	●	○	○	◑	●	●	◑	●	●	●	○	○	●	○	○	○
4.9 Solidification/Stabilization	●	●	◑	○	●	●	●	●	○	○	◑	◑	○	●	●	○
3.3 In Situ Thermal Treatment																
4.10 Thermal Treatment	●	○	○	○	●	◑	●	●	●	●	●	●	●	○	○	○
3.4 Ex Situ Biological Treatment (assuming excavation)																
4.11 Biopiles	●	●	●	●	●	●	◑	●	●	●	◑	◇	●	○	○	○
4.12 Composting	●	●	●	●	●	●	◑	●	◑	◑	◑	◇	●	○	○	●
4.13 Landfarming	●	●	●	●	●	●	◑	●	◑	◑	◑	◇	●	○	○	◇
4.14 Slurry Phase Biological Treatment	●	○	○	○	◑	◑	◑	●	◑	●	●	◇	●	◇	○	●
3.5 Ex Situ Physical/Chemical Treatment (assuming excavation)																
4.15 Chemical Extraction	●	○	○	○	◑	◑	●	●	◑	◑	●	●	◑	●	○	◑
4.16 Chemical Reduction /Oxidation	●	◑	◑	○	●	◑	●	●	◑	◑	●	●	◑	●	○	◑
4.17 Dehalogenation	●	◑	○	○	○	◑	●	●	○	●	○	●	○	○	○	◑
4.18 Separation	●	◑	○	◑	●	◑	●	●	◑	◑	◑	◑	○	◑	○	○
4.19 Soil Washing	●	○	○	○	●	◑	●	●	◑	◑	◑	◑	○	◑	○	○
4.20 Solidification/Stabilization	●	●	◑	○	●	●	●	●	○	○	◑	◑	○	●	●	○
3.6 Ex Situ Thermal Treatment (assuming excavation)																
4.21 Hot Gas Decontamination	○	●	○	○	●	●	●	◑	○	○	○	○	○	○	○	○
4.22 Incineration	●	●	○	○	◑	○	●	●	●	●	●	●	●	○	○	●
4.23 Open Burn/Open Detonation	●	●	○	○	●	●	●	●	○	○	○	○	○	○	○	●
4.24 Pyrolysis	●	●	○	○	○	○	●	●	◑	◑	●	●	●	○	○	○
4.25 Thermal Desorption	●	●	○	○	◑	◑	●	●	●	●	●	●	●	○	○	●
3.7 Containment																
4.26 Landfill Cap	●	●	◑	○	●	●	○	●	◑	◑	◑	◑	◑	◑	○	◑
4.27 Landfill Cap Enhancements/Alternatives	●	●	◑	○	●	●	○	●	◑	◑	◑	◑	◑	◑	○	◑
3.8 Other Treatment																
4.28 Excavation, Retrieval, Off-Site Disposal	●	●	●	●	●	◇	●	●	◑	◑	◑	◑	◑	◑	○	◑
Ground Water, Surface Water, and Leachate																
3.9 In Situ Biological Treatment																
4.29 Enhanced Bioremediation	●	●	○	◑	◑	●	◇	●	●	◇	●	◑	●	◇	○	◑
4.30 Monitored Natural Attenuation	●	●	○	◑	◑	●	◇	●	●	◑	◑	◑	●	○	○	○
4.31 Phytoremediation	●	●	●	●	○	●	○	◑	◑	◑	◑	◑	◑	◇	○	○
3.10 In Situ Physical/Chemical Treatment																
4.32 Air Sparging	●	●	●	●	●	●	●	●	●	◑	◑	◑	●	○	○	○
4.33 Bioslurping	●	◑	●	●	◑	●	◑	●	●	◑	●	●	●	◑	○	○
4.34 Chemical Oxidation	●	●	○	◑	◑	◑	●	●	●	◑	○	◑	○	◇	○	◑
4.35 Directional Wells (enhancement)	●	●	◑	○	◑	◑	◑	●	◑	◑	◑	◑	◑	◑	○	◑
4.36 Dual Phase Extraction	●	○	○	○	◑	◑	◑	●	◑	●	●	●	●	○	○	○
4.37 Thermal Treatment	●	○	○	○	◑	◑	●	●	◑	●	●	●	●	○	○	○
4.38 Hydrofracturing Enhancements	●	◑	●	●	●	◑	●	●	◑	◑	◑	◑	◑	◑	○	◑
4.39 In-Well Air Stripping	●	◑	◑	○	◑	◑	○	●	◑	◑	◑	○	◑	○	○	○
4.40 Passive/Reactive Treatment Walls	●	●	◑	○	●	◑	○	●	●	●	●	●	◑	◇	○	●
3.11 Ex Situ Biological Treatment																
4.41 Bioreactors	●	●	◑	○	◑	◑	○	●	●	●	●	◇	●	○	○	●
4.42 Constructed Wetlands	●	●	◑	○	◇	◑	◇	○	◑	◑	◑	◇	◑	●	○	●
3.12 Ex Situ Physical/Chemical Treatment (assuming pumping)																
4.43 Adsorption/ Absorption	●	●	○	◑	◑	○	○	●	◑	◑	◑	◑	○	●	◇	○
4.44 Advanced Oxidation Processes	●	◑	○	○	◑	◑	○	●	●	●	●	●	●	◇	◇	●
4.45 Air Stripping	●	◑	○	◑	●	●	○	●	●	●	○	○	○	○	○	○
4.46 Granulated Activated Carbon/Liquid Phase Carbon Adsorption	●	◑	○	◑	●	◑	○	●	●	●	●	●	●	◇	○	◇
4.47 Groundwater Pumping/Pump & Treat	●	◑	○	○	●	○	○	●	◑	◑	◑	◇	◑	○	◑	○
4.48 Ion Exchange	●	◑	○	○	●	◑	○	●	○	○	○	○	○	●	◑	○
4.49 Precipitation/Coagulation/Flocculation	●	◑	◑	○	●	◑	○	●	○	○	○	○	○	●	◑	○
4.50 Separation	●	◑	○	○	●	○	●	●	●	●	●	●	●	◇	◇	○
4.51 Sprinkler Irrigation	●	●	●	●	●	○	○	●	●	●	○	○	○	○	○	○
3.13 Containment																
4.52 Physical Barriers	●	●	◑	○	●	●	○	●	●	●	●	●	●	●	◑	●
4.53 Deep Well Injection	●	●	●	●	◑	●	○	●	◑	◑	◑	◑	◑	◑	◑	◑
3.14 Air Emissions/Off-Gas Treatment																
4.54 Biofiltration	●	N/A	●	●	◇	●	●	○	●	◇	◇	◇	●	○	I/D	◇
4.55 High Energy Destruction	○	N/A	I/D	I/D	○	◑	I/D	◑	●	●	●	●	◑	◑	I/D	○
4.56 Membrane Separation	○	N/A	I/D	I/D	○	◑	I/D	◑	●	●	◑	◑	◑	○	I/D	◑
4.57 Oxidation	●	N/A	●	●	●	●	I/D	●	●	●	●	●	●	○	I/D	◑
4.58 Scrubbers	●	N/A	◑	○	●	●	I/D	●	○	○	○	○	○	●	I/D	I/D
4.59 Vapor Phase Carbon Adsorption	●	N/A	●	●	●	●	I/D	●	●	●	●	●	●	◑	I/D	●

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

Factors		● Above Average	◑ Average	○ Below Average	Other
Development Status Scale status of an available technology		Implemented as part of the final remedy at multiple sites, well documented, understood, etc.	Has been implemented at full scale but still needs improvements, testing, etc.	Not been fully implemented but has been tested (pilot, bench, lab scale) and is promising	◇ Level of Effectiveness highly dependent upon specific contaminant and its application/ design
Treatment Train Is the technology only effective as part of the treatment train?		Stand-alone technology (not complex in terms of number of media/treatment technologies, maybe one "routine" technology in addition)	Relatively simple (two-car train or so), and well understood, widely applied, etc.	Complex (more technologies, med a to be treated, generates excessive waste, etc.)	
Relative overall cost and performance	O&M Operation and Maintenance Intensive	Low degree of O&M intensity	Average degree of O&M intensity	High degree of O&M intensity	
	Capital Capital Intensive	Low degree of capital investment	Average degree of capital investment	High degree of capital investment	
	System Reliability/Maintainability The expected range of demonstrated reliability and maintenance relative to other effective technologies	High reliability and low maintenance	Average reliability and average maintenance	Low reliability and high maintenance	N/A "Not Applicable"
	Relative Costs Design, construction, and operations and maintenance (O&M) costs of the core process that defines each and pre-and post-treatment	Low degree of general costs relative to other options	Average degree of general costs relative to other options	High degree of general costs relative to other options	I/D "Insufficient Data"
	Time Time required to clean up a "standard" site using the technology — in situ soil	Less than 1 year	1-3 years	More than 3 years for in situ soil	
	Time — ex situ soil	Less than 0.5 year	0.5-1 year	More than 1 year for ex situ soil	
	Time — groundwater	Less than 3 years	3-10 years	More than 10 years for water	
Availability Number of vendors that can design, construct, and maintain the technology		More than 4 vendors	2-4 vendors	Fewer than 2 vendors	
Contaminants Treated Contaminants are classified into eight groups: - Nonhalogenated VOCs - Halogenated VOCs - Nonhalogenated SVOCs - Halogenated SVOCs - Fuels - Inorganics - Radionuclides - Explosives		Effectiveness Demonstrated at Pilot or Full Pilot or Full Scale	Limited Effectiveness Demonstrated at Pilot or Full Scale	No Demonstrated Effectiveness at Pilot or Full Scale	Same as above

Previous Section	Home	Screen Matrix	Table of Contents	Synonym List	Next Section

Table 3-3 Definition of Matrix Treatment Technologies

Technology	Description
Soil, Sediment, and Sludge Technologies	
3.1 In Situ Biological Treatment	
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.
Enhanced 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.
Landfarming	Contaminated soils are periodically turned over or tilled into the soil to aerate the waste.
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.
Phytoremediation	Phytoremediation is a set of processes that use plants to clean contamination in soil, ground water, surface water, sediment, and air.
3.2 In Situ Physical/Chemical Treatment	
Electrokinetic Separation	The Electrokinetic Remediation (ER) process removes metals and organic contaminants from low permeability soil, mud, sludge, and marine dredging. ER uses electrochemical and electrokinetic processes to desorb, and then remove, metals and polar organics. This in situ soil processing technology is primarily a separation and removal technique for extracting contaminants from soils.
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 ground water to raise the water table into the contaminated soil zone. Contaminants are leached into the ground water, 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).
3.3 In Situ Thermal Treatment	
Thermal Treatment	Steam/hot air injection or electromagnetic/fiber optic/radio frequency/electrical conduction heating is used to increase the mobility of volatiles and facilitate extraction. The process includes a system for handling off-gases.
Technology	**Description**
Soil, Sediment, and Sludge Technologies	
3.4 Ex Situ Biological Treatment	
Biopiles	Excavated soils are mixed with soil amendments and placed in aboveground enclosures. Processes include prepared treatment beds, biotreatment cells, soil piles, and composting.
Composting	Contaminated soils are 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.
Genetically Engineered Organisms	Genetically engineered organisms refer to microorganisms that have undergone external processes by which its basic set of genes has been altered.
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.
3.5 Ex Situ Physical/Chemical Treatment	
Chemical Extraction	Waste contaminated soil and extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.
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.
Dehalogenation	Reagents are added to soils contaminated with halogenated organics. The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.

Separation	Separation techniques concentrate contaminated solids through physical and chemical means. These processes seek to detach contaminants from their medium (i.e., the soil, sand, and/or binding material that contains them).
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.
Solar Detoxification	Solar detoxification is a process that destroys contaminants by using the ultraviolet energy in sunlight.
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).
Technology	**Description**
Soil, Sediment, and Sludge Technologies	
3.6 Ex Situ Thermal Treatment	
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.
Open Burn/Open Detonation	In open burn 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 open detonation 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.
Thermal Desorption	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.
3.7 Containment	
Landfill Cap	Landfill caps are used for contaminant source control.
Water Harvesting Vegetative Cover	Water harvesting vegetative cover is a land cover that, through engineered vegetative design, enhances evaporation, plant

	transpiration, and moisture removal from the soil.
3.8 Other Treatment Technologies	
Excavation, Retrieval, and Off-Site Disposal	Contaminated material is removed and transported to permitted off-site treatment and disposal facilities. Pretreatment may be required.
Technology	**Description**
Ground Water, Surface Water, and Leachate Technologies	
3.9 In Situ Biological Treatment	
Co-metabolic Treatment	Injection of a dilute solution of liquids and/or gases (e.g., toluene, methane or oxygen) into the contaminated ground water zone to enhance the rate of methanotrophic biological degradation of organic contaminants.
Enhanced Biodegradation	The rate of biodegradation of organic contaminants by microbes is enhanced by increasing the concentration of electron acceptors in ground water. Oxygen is the main electron acceptor for aerobic biodegradation. Nitrate can serve as an alternative electron acceptor under anaerobic conditions.
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.
Phytoremediation of Organics	Phytoremediation is a set of processes that uses plants to clean contamination, particularly organic substances, in ground water and surface water.
3.10 In Situ Physical/Chemical Treatment	
Aeration	Aeration is the process by which the area of contact between water and air is increased, either by natural methods or by mechanical devices.
Air Sparging	Air is injected into saturated matrices to remove contaminants through volatilization.
Bioslurping	Bioslurping combines the two remedial approaches of bioventing and vacuum-enhanced free-product recovery. Bioventing stimulates the aerobic bioremediation of hydrocarbon-contaminated soils. Vacuum-enhanced free-product recovery extracts LNAPLs from the capillary fringe and the water table.
Directional Wells	Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling.
Dual Phase Extraction	A high vacuum system is applied to simultaneously remove various combinations of contaminated ground water, separate-phase petroleum product, and hydrocarbon vapor from the subsurface.
Fluid/Vapor Extraction	A high vacuum system is applied to simultaneously remove liquid and gas from low permeability or heterogeneous formations.
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	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.
In-Well Air Stripping	Air is injected into a double screened well, lifting the water in the well and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. Once in the well, some of the VOCs in the contaminated ground water are transferred from the dissolved phase to the vapor phase by air bubbles. The contaminated air rises in the well to the water surface where vapors are drawn off and treated by a soil vapor extraction system.
Passive/Reactive 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.
Technology	**Description**
Ground Water, Surface Water, and Leachate Technologies	
3.11 Ex Situ Biological Treatment	
Bioreactors	Contaminants in extracted ground water are put into contact with microorganisms in attached or suspended growth biological reactors. In suspended systems, such as activated sludge, contaminated ground water 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.
Constructed Wetlands	The constructed wetlands-based treatment technology uses natural geochemical and biological processes inherent in an artificial wetland ecosystem to accumulate and remove metals and other contaminants from influent waters.
3.12 Ex Situ Physical/Chemical Treatment	
Adsorption/ Absorption	In liquid adsorption, solutes concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase.
Air Stripping	Volatile organics are partitioned from ground water by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.
Granulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption	Ground water 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.
Ion Exchange	Ion exchange removes ions from the aqueous phase by exchange with innocuous ions on the exchange medium.
Precipitation/ Coagulation/Flocculation	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.
Separation	Separation techniques concentrate contaminated waste water through physical and chemical means.
Sprinkler Irrigation	Wastewater is distributed over the top of the filter bed through which wastewater is trickled. The organic contaminants in wastewater are degraded by the microorganisms attached to the filter medium.
Ultraviolet 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.
3.13 Containment	
Deep Well Injection	Deep well injection is a liquid waste disposal technology. This alternative uses injection wells to place treated or untreated liquid waste into underground reservoirs where it will not cause environmental harm.
Ground Water Pumping	Ground water pumping is a component of many pump-and-Treat processes, which are some of the most commonly used ground water remediation technologies at contaminated sites.
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 ground water flow.
Technology	**Description**
Air Emissions/Off-Gas Treatment Technologies	
3.14 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.

Chemical Disposal Pit, Hill AFB, UT 1998 James T. Gibbs 614-424-6424	Bioventing Battelle Columbus, OH	Soil	TCE, DCB, BTEX	In situ		In situ	"Bioventing Nonpetroleum Hydrocarbons," Engineered Approaches for In Situ Bioremediation of Chlorinated Solvent Contamination. 1999. (p 7-14)
Reilly Tar Superfund Site, St. Louis Park, MN 1997 Dr. Paul McCauley 513-569-7444 mccauley.paul@epa.gov	Bioventing EPA National Risk Management Research Laboratory	Soil	PAHs	In situ		In situ	"Bioventing for Enhanced Degradation of PAHs," Tech Trends, Aug 1999
St. Louis Park, MN 1997 Paul McCauley 513-569-7444	Bioventing National Risk Management Research Laboratory Cincinnati, OH	Soil	Hydrocarbons	In situ		In situ	Bioventing (Air-Injection) [An EPA SITE Program document will be produced.]
Savannah River DOE Program Manager Kurt Gerdes (301) 903-7289	Bioventing	Soil & Ground water	TCE and PCE. Soil:10 ppm, GW: 1 ppm Disposal of solvents used to degrease nuclear fuel target elements.		Levels attained < 2 ppb		Capital: $150K + 200 man-hours per week
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 respiration in the monitoring wells.	In situ technique for non- and semi-volatile hydrocarbons	Degrada- tion up to 5,000 ppm/year. Apparatus is relatively non- intrusive.
Tyndall AFB, FL Armstrong Laboratory /EQW (904) 283-6208 DSN: 523-6208	Bioventing	Soil	Volatile hydrocarbons in vadose zone > 1,000 mg TPH/kg soil declined to < 30 mg TPH/kg soil	In situ		In situ	$15 -$20/m^3 ($12 -$15/yd^3
Eielson AFB, AK Armstrong Laboratory /EQW Kathy Vogel Tyndall AFB, FL (904) 283-6208 DSN: 523-6208	Bioventing	Soil	Volatile hydrocarbons	In situ		In situ	Average bioventing cost $10 -$15/yd^3
Hill AFB, UT AFCEE/Armstrong Laboratory /EQW Kathy Vogel (904)283-6208	Bioventing	Soil to a depth of 60 ft.	25,000 gallons of JP-4. Starting levels at 20,000 ppm TPH. 98% reduction. A pilot-scale demo is presently (1997) being performed to treat chlorinated solvents.	In situ		In situ	Average bioventing cost $10-$15/yd^3
Lowry AFB, Lt.COL Tom Williams 3415 CES/DEV Lowry AFB, CO 80230	Bioventing	Soil	Heating oil which contained relatively high concentration of TPH.	In situ		In situ	Capital: $28,500; Annual Operating: $32,875
DOI Tech Demo (USGS) Galloway Township, NJ 1988	Vapor extraction and bioventing design	Soil & ground water	Gasoline	AIRFLOW - an adaptation of the	MODFLOW to perform airflow simulations	None	Success dependent on ability to characterize air permeability.

Herbert T. Buxton (609) 771-3900				USGS ground water flow simulator	to predict well locations and pumping rates		
Former Chemical Drum Storage Pad, Rickenbacker Air National Guard Base, OH 1998 Wendy J. Davis-Hoover 513-569-7206 davis-hoover.wendy@epa.gov	In situ soil bio-remediation w/ Lasagna™ U.S. EPA Cincinnati	Soil	TCE	In situ		In situ	"In Situ Bioremediation Using Horizontal Lasagna™," Engineered Approaches for In Situ Bioremediation of Chlorinated Solvent Contamination. 1999. (p 263-267)
Savannah River Site Sanitary Landfill, Aiken, SC 1998 Robin L. Brigmon	In situ soil bio-remediation/ Westinghouse Savannah River Co. Aiken, SC	Soil	TCE, VC, DCE	In situ		In situ	Evaluation of Methanotrophic Bacteria During Injection of Gaseous Nutrients for In Situ Trichloroethylene Bioremed-iation in a Sanitary Landfill WSRC-MS-98-00854
Kennedy Space Flight Center, Cape Canaveral, FL 1998 Tom Rogers 409-693-0017	In situ soil bio-remediation/ Lynntech, Inc. College Station, TX	Soil	Chlorinated Solvents	In situ		In situ	Resource Guide for Electrokinetics Laboratory & Field Processes Applicable to Radioactive & Hazardous Mixed Wastes in Soil & Groundwater ... EPA 402-R-97-006 (p 59)
Radford Army Ammunition Plant, VA 1997 Dr. Tom Rogers 409-693-0017	In situ soil bio-remediation/ 1997 Lynntech, Inc. College Station, TX	Soil	Heavy Metals	In situ		In situ	Resource Guide for Electrokinetics Laboratory & Field Processes Applicable to Radioactive & Hazardous Mixed Wastes in Soil & Groundwater EPA 402-R-97-006 (p 56)
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 bio-remediation/ ABB Environ-mental Services	Soil (12 acres to 10 ft deep, about 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 place	The soil became saturated quickly during this project, creating surface pools. The specially designed tractor got stuck.
EPA Removal Action Roseville Drums, CA 2/12/88 to 11/9/88 Brad Shipley (415) 744-2287	In situ bio-remediation/ EPA removal contractor	Soil (14 yd^3)	Input: Dichloro-benzene - 4,000 ppm Phenol - 12,000 ppm	Additives to soil: manure, water	Tilling	Output: Dichloro-benzene -140 ppm Phenol - 6 ppm	Midnight dump on dirt road.
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 place	The biological treatment would have been more successful if the neutralization after the chemical treatment had been more complete. Tearing of the plastic sheets covering the soils allowed air in and prevented anaerobic activity.
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 bio-remediation)/ 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	Bio-remediation	Output: Toxaphene - 470 ppm Ethyl parathion - 56 ppm Methyl	Drum storage/disposal.

						parathion - 3 ppm	
Navy Demo Naval Communica- tion Station, Scotland 2/85 to 10/85 Deh Bin Chan (805) 982-4191	Biodecontami- nation of fuel oil spills	Soil	Fuel Oil	In situ; micro- organisms function best at 20-35 °C	In situ	In situ	Diesel fuel storage tanks and piping.
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	Inhibited by copper or high clay content.
Army Demo U.S. Army Construction Engineering Research Laboratory, IL Jean Donnelly (217) 352-6511	Biodegradation of oil contaminated soils	Soil	Motor oil/lubrication oil	In situ	Disk inoculant & nutrients into contaminated soil. Cover soil w/ventilated plastic sheeting.	In situ	Applicable to spills on air strips, roads, and parking lots.
Air Force Demo Kelly AFB, TX & Eglin AFB, FL Joe Laird (402) 221-7772	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 wells remove excess fluids	Site character- ization necessary to determine soil/chemical compatibility.
Formerly JimBo's Gas N'Goodies, Aiken, SC 1999 Jim Ullery 706-722-3490 JUllery@setechctr.org	In situ Biodegradation Southeastern Technology Center (STC)	Soil	BTEX	In situ		In situ	PHOSter Bioremediation Technology: Award- Winning Technology Demonstrated in Downtown Augusta setechctr.org/Environmental/phoster.htm
FAA Technical Center- Area D Atlantic County, NJ Carla Struble (212) 264-4595	Enhanced biodegradation	Nutrient addition and ground water reinjection in saturated soil (sand)	33,000 yd^3 Jet fuel NAPLs	In situ		In situ	Expected full scale $286K CAP and $200K O&M
Pinellas STAR Center, Largo, FL 1997 M.F. DeFlaun	Enhanced aerobic biodegradation Envirogen, Inc. Lawrenceville, NJ	Soil	Chlorinated Solvents	In situ		In situ	Performance Evaluation of an In Situ Anaerobic Biotreatment System for Chlorinated Solvents EPA 600-A-98-041
Eglin AFB, FL Alison Thomas (904) 283-6303	Enhanced anaerobic biodegradation	Fuel con- taminated aquifer.	4,000 ppb BTEX				Using nitrate as an alternative electron acceptor
French Limited Superfund Site, Crosby, TX Judith Black Remedial Project Manager U.S. EPA Region 6 (214)665-6937	Slurry-phase bioremediation	300,000 tons of soil and sludge	PCBs (up to 616 mg/kg), volatile organics (up to 400 mg/kg), penta- chlorophenol (up to 750 mg/kg), semivolatiles (up to 5,000 mg/kg) and metals (up to 5,000 mg/kg).	In situ		In situ	Total cost of $49,000,000 of which $26,900,000 directly related to treatment, $16,500,000 for before- treatment, $5,600,000 for after- treatment.
DOE Demo Savannah River Site, SC Nate Ellis (803) 952-4846 Brian Loony	Vegetation enhanced biodegradation	Soil	TCE, PCE & PAHs at 10,000 ppb	In situ	Root- associated micro- organisms degrade contaminants.	In situ	Pine trees are most effective. Depth limited to about 20 ft. $50,000/ acre.

(803) 752-5181							
Brookhaven National Laboratory 1998 USDOE	Phyto-remediation	Soil	Cs(137)	In situ		In situ	"Biomass Remediation System (TMS #251)," SCFA Midyear Review Report and Supporting Documentation, 1999
Whitewood Creek, SD 1998 Jerald R. Schnoor 319-335-5649 jschnoor@cgrer.uiowa.edu	Phyto-remediation University of Iowa	Soil	As, Cd	In situ		In situ	Phytostabilization Demonstra-tion, One Acre Test Plot, Mine Wastes, Phytoremediation: Technology Evaluation Report. GWRTAC TE-98-01 (p 8)
Dearing, KS 1998 G. Pierzynski 785-532-7209 gmp@ksu.edu	Phyto-remediation Kansas State University	Soil	Pb, Zn, Cd	In situ		In situ	Phytostabilization Demon-stration, One Acre Test Plot Abandoned Smelter, Barren Land, Phytoremediation: Technology Evaluation Report. GWRTAC TE-98-01 (p 8)
Trenton, NJ Site 1998 Burt Ensley 908-438-0900	Phyto-remediation Phytotech, Inc. Monmouth, NJ	Soil	Heavy Metals	In situ		In situ	Phytoextraction of Metal from Soil [An EPA SITE Program document will be produced.]
DOE Site, Ashtabula, OH 1997 Burt Ensley 908-438-0900	Phyto-remediation Phytotech, Inc. Monmouth, NJ	Soil	Inorganic Compounds	In situ		In situ	Rhizofiltration Demonstration, DOE Energy Wastes, Phytoremediation: Technology Evaluation Report. GWRTAC TE-98-01 (p 8)
Naval Surface Warfare Center, Dahlgren, Site 17	Phyto-remediation	Soil and Groundwater	Mercury (<0.14 ug/L)	Hybrid Poplar Trees Evergreen Trees		Pre-design	
Idaho National Engineering Laboratory (USDOE, Operable Unit 21)	Phyto-remediation	Soil	Chromium (NR) Cesium-137 (NR) Mercury (NR) Selenium (NR) Silver (NR) Zinc (NR)	Prairie Cascade Willows Kochia Scoparia		Operational	
Bofors Nobel (Operable Unit 1)	Phyto-remediation	Soil, Sludge, and Groundwater	Benzene	No Information		Pre-design	
Boarhead Farm	Phyto-remediation	Soil and Groundwater	Cadmium (5 ug/L, Groundwater) Nickle (100 ug/L, Groundwater) Benzene (0.5 mg/kg, Soil) Trichloroethene (0.4 mg/kg, Soil)	No Information		Design	
Aberdeen Proving Grounds (Edewood Area, J-Field Soil OU	Phyto-remediation	Soil and Groundwater	1,1,2,2-Tetrachloroethene (NR) Trichloroethane (NR)	Hybrid Poplar Trees Magnolia Trees Silver Maple Trees		Operational	
McCormick & Baxter **SUPERFUND Site**, Portland, OR (Wood treatment site) Steve Rock (513) 569-7149	Phyto-remediation	Shallow soil	PCP and PAHs	Perennial ryegrass	Site seeded and irrigation system installed		
Argonne National Laboratory M. Christina Negri, DOE, Office of Energy Research, (630) 252-9662	Phyto-remediation	Soils	Heavy metals				Project is also investigating the fate of chlorinated organic solvents in plant systems

Craney Island Fuel Terminal, U.S. Navy, Portsmouth, VA Dr. Stephanie Fiorenza, DoD/AATDF (713) 527-8101 x3338	Phyto-remediation	Soils (15 acres)	TPH	1) bermuda grass sod over-seeded with rye grass, 2) white clover, 3) tall fescue	The site is visited once per month during the growing season. Plots are weeded, mowed, and fertilized. Sampling is conducted monthly or bimonthly for total petroleum hydrocarbons (TPH) and nutrients in soil, above- and below-ground biomass development, and contaminants in soil pore water.		
EPA S.I.T.E. Program, Ogden, Utah Steve Rock (513) 569-7149	Phyto-remediation; Chevron Research, Phytokinetics, Inc	Soil and ground water	Petroleum spill	Poplar trees, juniper trees, alphalfa, and fescue	Planted in three rows (six feet apart) perpendicular to ground water flow to form subsurface interceptor barrier to the saturated zone		Plants used: Alfalfa, Poplar Juniper, Fescue
Ohio (Former metal plating site) Steve Rock (513) 569-7149	Phyto-remediation; Phytotech, Inc	Soil	Lead, chromium, and hexavalent chrome	Indian mustard plants	Two to three plantings per year are expected	Plants will be harvested, then either disposed of or recycled for metals content	

Sources: *Innovative Treatment Technologies: Annual Status Report (Eighth and Tenth Editions, Nov. 1996 and Feb. 2001). Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America (1st and 2nd Editions, Aug 1996 and Jun 2000).*

Army Demo, U.S. Army Waterways Experiment Station, Baton Rouge Louisiana Robert Marks, General Manager Electrokinetics Inc. Louisiana Business and Technology Center Louisiana State University, Suite 155 South Stadium Drive Baton Rouge, Louisiana 70803-6100 (504) 388-3992 Fax: (504) 388-3928	Electro-Klean Electrical Separation Electrokinetics , Inc.	Soil	Lead	In situ	Conditioning fluids may be added or circulated at the electrodes to enhance the electro-chemistry of the process	Contaminants are electroplated on the electrodes or separated in a post-treatment unit	
An Underground Storage Tank Spill Walter Loo Environmental & Technology Services 2081 15th Street San Francisco, CA 94114 (415) 861-0810 Fax: (415) 861-3269	Electrokinetic Enhancement with Bioventing/ Environment & Technology Services	Soil	BTEX	Direct current was applied through 56 electrodes installed in the upper clay layer of this 2,400 square foot gasoline contaminated site to move contaminants and water down 15 feet into dense cemented conglomerate sandstone	In situ	Contaminants were removed from the dense cemented conglomerate sandstone by bioventing	Bioventing, enhanced by electro- kinetics, reportedly reduced gasoline levels of 100-2,200 ppm to well below the target of 100 ppm after about 90 days at a cost of about $50/ton
DOE Demo, Oak Ridge K-25 facility, Tennessee Henry L. Lomasney Isotron Corporation 13152 Chef Menteur Highway New Orleans, LA 70129 (504) 254-4624 Fax: (504) 254-5	Electrokinetic Extraction/ Isotron Corporation	Soil	Uranium and Organic Contaminants		In situ		
DOE Demo, Sandia National Laboratories Chemical Waste Landfill Eric R. Lindgren Sandia National Laboratory P.O. Box 5800, Mail Stop 0727 Albuquerque, NM 87185 (505) 844-3820 Fax: (505) 844-1480	ElectroKinetic Extraction/ Sandia National Laboratories and Sat-Unsat, Inc.	Soil	Chromium	Soluble chromium concen- trations range from 25 to 10,000 ppm with the upper limit at 15 feet below ground surface	In situ	Contaminants arriving at the electrodes will be removed using a vacuum system	
EPA/DOE Demo, DOE Gaseous Diffusion Plant, Paducah, Kentucky Sa Ho or B. Mason/ Hughes	Electrokinetic Separation with Hydraulic Fracturing	Soil (Clay)	TCE	In situ	Highly permeable subsurface sorption zones will be created in a vertical configuration by hydraulic fracturing or		

Environmental Sciences Center Monsanto Company St. Louis, MO 63167 (314) 694-5179/ (314) 694-1466 Fax: (314) 694-1531 Steven J. Bossart U.S. Department of Energy (304) 285-4643					similar technology followed by the introduction of certain sorbents		
DOE Demo, Old TNX Basin, Savanah River Site, South Carolina Henry L. Lomasney Isotron Corporation 13152 Chef Menteur Hwy New Orleans, LA 70129 (504) 254-4624 Fax: (504) 254-5172 Jane P. Bibler Westinghouse Savannah River Company 803-725-5276	ElectroKinetic Separation/ Isotron Corporation	Unsaturated Soil	Mercury, Lead, Chrome	In situ	An Electrosorb® process is used with a patented cylinder to control buffering conditions in situ and an ion exchange polymer matrix called Isolock® to trap metal ions		Preliminary results indicate that at the 5 ppm mercury concentrations found at the site and other conditions, mercury will be difficult to remediate. However, the process is showing good results on lead and chrome.
Naval Facility Pearl Harbor, HI 1999 Stephen R. Clark 510-704-2940 EPA NRMRL Thomas Holdsworth 513-569-7675	Electrokinetic Separation Geokinetics	Soil	Fuel Oil	In situ		In situ	Electrokinetic Heating [An EPA SITE Program document will be produced.]
Naval Facility Pearl Harbor, HI 1999 Stephen R. Clark 510-704-2940 EPA NRMRL Jack Hubbard 513-569-7507	Electrokinetic Separation Geokinetics	Soil	Heavy Metals	In situ		In situ	Electrokinetics [An EPA SITE Program document will be produced.]
Kennedy Space Flight Center, Cape Canaveral, FL 1998 Tom Rogers 409-693-0017	Electrokinetic Separation Lynntech, Inc. College Station, TX	Soil	Chlorinated Solvents	In situ		In situ	Resource Guide for Electrokinetics Laboratory & Field Processes Applicable to Radioactive & Hazardous Mixed Wastes in Soil & Groundwater... EPA 402-R-97-006 (p 59)
U.S. Army,firing range, LA Yalcin Acar, Electrokinetics Inc. Louisiana State University	Electrokinetic Separation	Soil	Beginning Levels: Lead 4,500 mg/kg Levels attained: 300 mg/kg in 30 weeks				
X-231A Site, Portsmouth Gaseous Diffusion Plant, OH 1998 513-556-2526	Fracturing L.D. Murdoch FRx, Inc.	Soil	NAPLs, DNAPLs	In situ		In situ	X-231A: A Demonstration of In-Situ Remediation of DNAPL Compounds in Low Permeability Media by Soil

ORNL/Colorado School of Mines R.L. Siegrist rsiegris@mines.edu	Cincinnati, OH						Fracturing with Thermally Enhanced Mass Recovery or Reactive Barrier Destruction: Dense Non-Aqueous Phase Liquids ORNL/TM-13534
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 rate increased, concentration remained constant	HGI results inconclusive, PCE increased air flow rate 600%.
Robert Gray Army Airfield, Fort Hood, TX 1997 Kathy Balshaw-Biddle Fax: 713-285-5948	Hydraulic fracturing Fluor Daniel GTI Irvine, CA Jay Dablow Rice University, Houston, TX AATDF	Soil	SVOCs, JP-8 Jet Fuel	In situ		In situ	Remediation of Tight Soils: Hydraulic Fracture, Steam & Electro-Heating AATDF TR-98-12 & TR-98-14
EPA Demo Oak Brook, IL & Dayton, OH 1991 Naomi Barkley (513) 569-7854 Larry Murdock (513) 569-7897	Hydraulic fracturing and bioremediation	Soil	Rate of bioremediation increased 75% for BTEX, 77% for TPH	In situ	Water infiltration into vapor extraction area should be prevented	Fracture growth is measured through the deformation of the ground surface	Sand-laden slurry pumped into soil to increase permeability.
Marcus Hook, PA John Schuring or Peter Lederman Hazardous Substance Management Research Center(201) 596-5849/ 2457	Pneumatic Fracturing	Soil		In situ		In situ	
Laramie Tie Plant, WY	Soil Flushing	Soil	Creosote contamination. Total extractable organics = 93,000 mg/kg	In Situ		In Situ	
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 MEK6 ppm Ethylbenzene 23 ppm total xylene 0.2 ppm PCE	24 hours/day	None	Extracted vapor treated with gas phase carbon adsorption. Entrained (suspended) water treatment by the existing on-site UV-hydrogen peroxide treatment plant	

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 canister, air stripping for pump and treat	Re-evaluated the remediation in 1994.
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 emissions vented to atmosphere	Design specifications critical.
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 carbon was regenerated (and eventually incinerated)	Initial estimate of 7,000 lb of VOCs product too low. Treatment equipment undersized. Needed better quantification of VOCs in soils to design appropriate size. Plan for enhancing system to deal with saturated soils and free product.
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; approxi-mately 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 phase carbon adsorption	Sampling indicated the presence of TCE mainly in the soil gas samples and not the soil samples.
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 emissions captured on vapor phase carbon	

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 sent off-site for treatment. Vapors captured and put through a knock out pot and incinerated.	System was successful in decreasing concentration to cleanup goals. Had difficulties because fluctuation of shallow ground water decreased the efficiency, less vapors and more water.
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 approxi-mately 11,000 lb of vapors and 4,000 lb of condensate	Off gas vapors were thermally oxidized	TPH were present but were too heavy to volatilize. Would recommend combining SVE with in situ bioremediation to treat contaminants that could not be extracted with the SVE.
DOE Mound Facility, Miamisburg, OH 1997 James Johnson 937-847-5234 james.o.johnson@em.doe.gov	In situ air stripping DOE Ohio Sites Technology Coordination Group (STCG)	Soil	VOCs		In Situ	In Situ	Demonstrated High Vacuum Extraction www.ohio.doe.gov/oh-stcg
Dry Cleaning Facilities, Hutchinson, KS 1997 Douglas Dreiling 316-941-3921	In situ air stripping Kansas Department of Health and Environment	Soil	PCE		In Situ	In Situ	"Multi-Site Comparison of Chlorinated Solvent Remediation Using Innovative Technology," Physical, Chemical, & Thermal Technologies: Remediation of Chlorinated & Recalcitrant Compounds, 1998 (p 247-252)
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 averaged 110 lb of VOCs/day	Works best in sandy soils.
Former Industrial Facility, Sonoma, CA 1998 Christopher Nelson 303-231-8912 cnelson@gtionline.com	Chemical Oxidation Fluor Daniel GTI, Inc. 1527 Cole Blvd. Golden, CO 80401	Soil	PCP, PAHs		In Situ	In Situ	Field Applications of In Situ Remediation Technologies: Chemical Oxidation EPA 542-R-98-008 (p 22)
U.S. Army Cold Regions Research & Engineering Laboratory, Hanover, NH 1997 Daniel McKay 603-646-4738 dcmkay@crrel.usace.army.mil	Chemical Oxidation U.S. Army CRREL 72 Lyme Rd. Hanover, NH 03755	Soil	TCE		In Situ	In Situ	"In Situ Oxidation of Trichloroethylene Using Potassium Permanganate. Part 2: Pilot Study," in Physical, Chemical, & Thermal Technologies: Remediation of Chlorinated &

							Recalcitrant Compounds, 1998
Westinghouse Savannah River Site, Aiken, SC 1997 Karen M. Jerome 803-725-5223 karen.jerome@srs.gov	Chemical Oxidation Westinghouse Savannah River Co	Soil	TCE, PCE		In Situ	In Situ	Final Report for Demonstration of In Situ Oxidation of DNAPL Using the Geo-Cleanse Technology WSRC-TR--97-00283
Portsmouth Gaseous Diffusion Plant, Piketon, OH 1997 Dr. Robert L. Siegrist 303-273-3490 rsiegris@slate.mines.edu	Chemical Oxidation Colorado School of Mines Golden, CO	Soil	TCE		In Situ	In Situ	A Full-Scale Demonstration of In Situ Chemical Oxidation through Recirculation at the X-701B Site ORNL/TM-13556
Canadian Forces Base Borden, Ontario, Can 1997 Dr. Neil Thomson 519-885-1211 ext. 2111 nthomson@uwaterloo.ca	Chemical Oxidation University of Waterloo Waterloo, Ontario	Soil	TCE, PCE		In Situ	In Situ	Field Applications of In Situ Remediation Technologies: Chemical Oxidation EPA 542-R-98-008 (p 13)
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	Contaminants are treated with a catalytic oxidation unit prior to atmospheric release	Ineffective for removal of semivolatiles and metals. Does not work in saturated zone.
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 media method, so the waste is not destroyed	Soil venting may provide oxygen for biodegradation.
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 stream	Noise complaints required evening and weekend shutdown.
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 control required	Dual extraction of ground water and vapor possible.
Army Demo Luke AFB, AZ	SVE	Soil	BTEX (16, 183, 84, 336 ppm) and TRPH (1,300 ppm)	In situ - two 60-ft extraction wells at 100 scfm	In situ	Carbon air treatment, residual condensate generated at	Also can be used to enhance biodegradation.

1992 Jerome Stolinsky (402) 221-7170						8 gpd and incinerated	
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 emissions treated in biofilter if required	Network of injection and extraction wells to enhance biodegradation.
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 oxidation of vapors - 99.8% destruction	Simultaneous vapor/ ground water extraction.
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 treated by thermal burner or catalytic oxidation. Entrained water treated off-site	Also can be used to enhance biodegradation.
Groveland Wells Superfund Site Groveland, MA Mary Stinson EPA Technical Support Branch, RREL (908) 321-6683	Soil Vapor Extraction Terra Vac (714) 252-8900	Soil	3-350 ppm TCE Treated to non-detect to 39 ppm TCE	In situ		In situ	$30 to $75 per metric ton ($30 to $70 per ton) of soil
Letterkenny AD Chambersburg, PA USAEC ETD Bldg. 4435 APG, MD 21010 (410) 671-2054	Soil Vapor Extraction	Soil(2,000 yd^3) treated.	> 1,000 ppm total VOCs	In Situ	Large-scale (>50 vents) system.		$2M design, install, and operation.
Commence- ment Bay, South Tacoma Channel, Tacoma, WA Phil Stoa, U.S. Army Corps of Engineers Seattle District	Soil Vapor Extraction with an on-site solvent recovery system	98,203 cubic yards of soil treated.	10 to 100 mg/kg of VOC in top soil; 6,200 to 19,000 mg/kg of PCE in deep soil 571,000 pounds of VOCs in unsaturated zone.	In Situ			Total Capital Cost: $5,313,973; Annual Operating Cost: $100,000.
Fairchild Semiconductor Corporation Superfund Site, San Jose, CA Belinda Wei U.S. EPA Region 9	One of the earliest full-scale SVE used in a site with complex hydrogeology	42,000 cubic yards of soil	Up to 4,500 mg/kg of total solvents in soil.		39 extraction wells to treat		Capital: $2,100,000; Total Operating & Maintenance: $1,800,000 for 18 months. $93 per cubic yard soil treated
Hastings Ground Water Contamination Superfund Site, Well #3 Subsite, Hastings, NE Diane Easley (RPM) U.S. EPA Region 7	Full-scale SVE	185,000 cubic yards of soil.	Up to 1,234 ppm of tetrachloride		10 extraction wells.		Total cost of $369,628. $2 per cubic yard soil treated.

SMS Instruments Superfund Site, Deer Park, NY Abram Miko Fayon Remedial Project Manager U.S. EPA Region 2: (212) 264-4706	Full-scale SVE system	1,250 cubic yards of soil treated.	Up to 1,200 mg/kg for volatiles and 1,800 mg/kg for semivolatiles Treated to: <0.5 mg/kg for volatiles and <5.5 mg/kg for semivolatiles		Horizontal vapor extraction wells and a process control system. 2 extraction wells		Total cost: $450,521. $360 per cubic yard of soil treated.
Pottery Sites, Roseville/ Crooksville, OH 1998 Jim Barthel 303-215-6620	In situ solidification and stabilization Rocky Mountain Remediation Services	Soil	Pb	In Situ		In situ	Envirobond Soil Amendment [An EPA SITE Program document will be produced.]
EPA *SITE* Demo Hialeah, FL 1988-90 Mary Stinson (908) 321-6683 Jeff Newton (316) 269-2660	In situ solidification and stabilization	Wet or dry soil, sludge, sediment	PCBs, inorganic and organic compounds	Slurry injection with auger rotating at 15 rpm	Mixing, binding agent is modified for each waste	PCB immobi-lization is likely but not confirmed	Estimated costs $111/ton using a commercial 4 auger unit.
Georgia Institute of Technology, Atlanta, GA 1997 R.F. Schumacher	In situ vitrification Westinghouse Savannah River Co. Aiken, SC	Soil	Radioactive Wastes		In situ		Demonstration of In Situ Plasma Vitrification Technology for Savannah River Site Contaminated Soils WSRC-TR-97-0182
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 treatment system removes pollutants (by quenching, scrubbing, heating, filtration)	Organics destroyed; inorganics incorporated in resultant mass.
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 destroyed; inorganics incorporated in resultant mass	Lower potential risk -- contaminants are not brought to the surface. $300 $450/ton
EPA Demo Douglassville, PA	Solidification/ Stabilization: Chemical	Soil & sludge	Organic compounds, heavy metals, oil, & grease	In/ex situ. Sediments -- underwater. Batch	Blending with cement or fly ash,	Treated material hardens to a	Reagent formulation can be adjusted to specific contaminant.

10/87 Paul R. DePercin (513) 569-7797 Ray Funderburk (903) 545-2002	treatment & immobilization			process at 120 tons/hour	water, and "Chloranan"	concrete-like mass	

Sources: *Innovative Treatment Technologies: Annual Status Report (Eighth and Tenth Editions, Nov. 1996 and Feb. 2001). Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America (1st and 2nd Editions, Aug 1996 and Jun 2000).*

DOE Demo LLNL, CA 1993 Roger D. Aines, Robin L. Newmark (415) 423-7184 or 3644	Dynamic underground stripping	Concen- trated under ground plumes	Organics	In situ injection pressure controlled to increase with depth	Combination of steam injection and 3-phase soil heating	Organics volatilized and extracted in a vapor stream	Real time monitoring is used for process control.
Former Fire Training Site, Kirtland AFB, Albuquerque, NM 1997 Dr. David E. Daniel, PI 217-333-1497 dedaniel@uiuc.edu	Radio frequency (RF) thermal soil decon- tamination Brown and Root Environmental Oak Ridge, TN KAI Technologies, Inc. Portsmouth, NH University of Illinois	Soils	TPH, DRO	In situ			Enhanced Soil Vapor Extraction with Radio Frequency Heating AATDF TR-98-4; TR-98-9
Air Force Demo Volk Field ANGB, WI 1985, 1989, 1993 Paul F. Carpenter (904) 523-6022	Radio frequency (RF) thermal soil decon- tamination	Soils	Solvents & volatile & semivolatile petroleum hydrocarbons 94-99% decon- tamination in 12 days	Power source is 45 kW electric-magnetic generator	Heating, volatilization	Off gas captured at surface or through electrodes	Advantages: 1. No excavation required. 2. Equipment is portable. Limitations: 1. High moisture requires excessive power. 2. Large buried metal objects void method.
Groundwater Remediation Field Labora-tory (GRFL), Dover AFB, DE 1997 Theresa Bergsman 509-376-3638	Six-phase soil heating Battelle Pacific Northwest Laboratory (PNL) Richland, WA	Soils	DNAPLs	In situ			Six-Phase Heating™ Application Analysis Report: Aquifer Heating & DNAPL Treatment, Dover Air Force Base, Delaware--Executive Summary
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 must be treated before release	Sufficient soil moisture needed near electrodes to avoid excessive drying.

Hill AFB, UT 1997 Dr. Lloyd Steward 415-641-9044	Thermally enhanced vapor extraction Praxis Environmental Services San Francisco, CA Dr. Lloyd Steward 415-641-9044	Soils	NAPLs, Chlorinated Solvents, Weathered Fuels	In situ			Steam Injection/Vacuum Extraction [An EPA SITE Program document will be produced.]
X-231A Site, Portsmouth Gaseous Diffusion Plant, OH 1997 R.L. Siegrist rsiegris@mines.edu	Thermally enhanced vapor extraction ORNL/Colorado School of Mines Golden, CO	Soils	NAPLs, DNAPLs	In situ			X-231A: A Demonstration of In-Situ Remediation of DNAPL Compounds in Low Permeability Media by Soil Fracturing with Thermally Enhanced Mass Recovery or Reactive Barrier Destruction: Dense Non-Aqueous Phase Liquids ORNL/TM-13534
Stroudsburg, PA 1997 James Speight 307-721-2011	Themal Enhanced Recovery Western Research Institute Laramie, WY	Soils	Oily Wastes	In situ			Contained Recovery of Oily Wastes [An EPA SITE Program document will be produced.]
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 must be treated	$15 to $20/ton depending on soil moisture and treatment temperature.
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 air treated with carbon. Treated water recycled in process.	No downward migration of contaminants during soil treatment.
EPA Demo LeMoore NAS, CA 1988 Paul DePercin	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 contaminants are either condensed or treated with extracted air or liquid	Can be adapted to prevent downward movement of DNAPLs.

(513) 569-7797							
EPA Demo San Fernando Valley Ground Water 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 Ground water 1,200 gpm Soil gas 300 ft/min	Ground water steam stripping tower and SVE of soil	Carbon should be regenerated every 8 hours	Has been in operation over 3 years.
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 separated by gravity water treatment	Only low concentrations of DNAPLs can be treated.
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 brought to surface	Biodegra- dation may follow this process.
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 contami- nation.	Vapors to thermal oxider	Ex situ application also possible.
Lockheed Aeronautical Systems Burbank, CA Norma Lewis EPA (513) 569-7665	Integrated ground water stripping and soil system.	Soil and Ground water	PCE 11 ppm Soil gas: Total VOC 6,000 ppm ground water: TCE 2.2 ppm 98-99.9% VOC removal			Off gas must be treated	$4.3M and $630,000 annual O&M for 1,000 gpm system
Kelly AFB, TX Paul Carpenter AL/EQW (904)283-6187	Two pilot-scale demos of RF heating: IITRI and KAI designs	Soil	>90% VOC and SVOC removal;			Off gas must be treated	< $100/ton in shallow clay

Sources: *Innovative Treatment Technologies: Annual Status Report (Eighth and Tenth Editions, Nov. 1996 and Feb. 2001). Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America (1st and 2nd Editions, Aug 1996 and Jun 2000).*

Marine Corps Air Ground Combat Center Twenty-Nine Palms, CA R.L. Biggers NFESC, (805) 982-2640	Biopile	Soil	Fuel from UST and spills - heap pile research project 702 ppm average TPH - beginning levels 234 ppm average-ending	Temperature, pressure, and moisture content are monitored.	Excavation		$36/m^3 ($27/yd^3)$
Mobil Terminal Buffalo, NY Robert Leary or Sal Calandra (716) 851-7220	Biopile	Soil	Gas, diesel, lead	11,500 m^3; non-native organisms added			
Naval Air Station Yorktown, VA 1999	Bioremediation (ex situ) Grace Bioremediation Technologies	Soil	Organic Explosives, Chlorinated Solvents				DARAMEND Soil Amendments to Remediate Explosives in Soils (Full Demonstration
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 approxi- mately 40 by 60 ft area. Constructed on poly barrier and clean sand base. Did some mixing.	Backfilled the soil into the excavation.	Island is now a wildlife refuge; has an endangered species.
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 months of operation, the TPH levels were 120 ppm	
Bioremediation Treatment Facility (BTF) at NAS North Island	Biopile	Soil	Petroleum hydrocarbon				For a typical petroleum UST site that generates 1,000 tons of contaminated soil, treatment at the BTF will save about $30,000 as compared to thermal desorption or soil washing at local facilities and more than $100,000 as compared to disposal at an off-site Class II landfill.
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 months of operation, the TPH levels were 120 ppm	
UMDA Hermiston, OR	Windrow Composting	Soil	Beginning level: 1,563 ppm TNT				$210/metric ton ($190/ton) for

USAEC (410)671-2054			953 ppm RDX 156 ppm HMX Levels attained: 4 ppm TNT 2 ppm RDX 5 ppm HMX				large-scale (20,000 tons) cleanup
LAAP Shreveport, LA USAEC (410)671-2054	Mechanical in-vessel composting	Soil	Beginning level: 5,200 ppm TNT 500 ppm RDX Levels attained: 20 ppm TNT 20 ppm RDX				
Cliff/Dow Disposal Site Marquet Ken Glatz (312) 886-1434	Composting	Soil (7,000 m^3)	PAHs, As, Cu, Pb, Hg				Destroyed only the lower molecular weight PAHs; did not reach safety level desired
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 concentrations: meso=376 mg/kg, therm=74 mg/kg. % reductions: TNT= 99.6/99.9 RDX= 94.8/99.1 HMX= 86.9/95.6	
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 collection from composting pads	
Army Demo Umatilla Depot Activity, OR Harry Craig (503) 326-3689	Aerobic composting optimization	Soil & sediment (10,969 yd^3)	TNT, HMX, RDX, Tetryl. TNT and RDX soil concentrations ranged from 100 to 2000 ppm, HMX from 1 to 100 ppm.	Maintain moisture content at 30-35%. Turning frequency was once every 24 hours for first 5 days, less frequent turning on subsequent days.	Mix with bulking agents & organic amendments	Runoff collection from composting pads	Reduced the levels of target explosives to below the cleanup goals at: 190 ppm for TNT and 227 ppm for RDX. Total cost $346 per ton from mobilization to demobilization. Cost specific to biological treatment is $181 per cubic yard soil treated.
Dubose Oil Products Co. Superfund, Cantonment, FL. Mark Fite (404) 562-8927	Composting	19,705 tons of soil	Contaminants concentrations: VOC ranged from 0.022 to 38.27 mg/kg; Total PAH from 0.578 to 367 mg/kg; PCP from 0.058 to 51 mg/kg.	Control of soil oxygen and moisture content, pH, and nutrients levels.	Systems for aeration, inoculum growth and application	Leachate collection, and wastewater treatment.	Cleanup goal met for all constituents. Total PAH in treated soil ranging from 3.3 to 49.9. Unit cost directly attributed to treatment was $266/ton.
Pilot-scale Demo; Letterkenny AD, Chambersburg, PA Richard Scholze, USACERL, (217) 373-3488	Genetically Engineered Organisms (White rot fungus)	PCP- treated ammu- nition boxes	425 ppm of PCBs; 30% removal but 80% removal in lab				PCP-treated ammunition boxes in less than ideal conditions.
Brookhaven Wood Preserving, MS; 1993 Richard Lamar,	Genetically Engineered Organisms (white rot fungus)	Soil (1/4 acre) PCP 700 ppm	PCBs, PAHs; Attained 89% PCP removal, 70% PAH removal	In situ	Tilling and watering; No nutrients were added	Air emmisions data showed no significant hazards due to soil tilling activities; Contaminated soil,	Levels of PCP and the target PAHs found in the underlying sand layer and the leachate from each

USDA, (608) 231-9469; John Glasser EPA RREL (513) 569-7568						underlying sand, and leachate had no significant contami- nation.	of the plots were insignificant, indicating low leachability and loss of these contaminants due to periodic irrigation of the soil and heavy rainfall; Levels of PCP, the target PAHs, and dioxins in the active air samples collected during the soil tilling events were insignificant, indicating a very low potential for airborne contaminant transport.
Bioremediation of PAH Contaminated Soils Environmental Protection Service, Environment Canada, Hull, Quebec (819) 953-0962	Genetically Engineered Organisms, Using White Rot Fungi GEOBAC Technologies Group, Inc.	Soil	Polyaromatic Hydrocarbons (PAH)				
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 material vegetated with grass (no cap)	Further information on this project is available from the Remedial Action Close Out Report. The vendor, RETEC, is expected to prepare a paper.
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 collection and treatment with granular activated carbon	This treatment used both bioremediation and soil flushing in one step.
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 Total PAH 12 ppm Benzo(a)-pyrene	Wood preserving site.
Lowry AFB, Denver, CO Lt. Tom Williams, 3415 CES/DEV Lowry AFB, CO 80230	Land Treatment Engineering Science, Inc. Denver, CO	Soil (5,400 yd^3)	BTEX < 100 mg/kg, Total Recoverable Petroleum Hydrocarbons (TRPH) upto 11,000 mg/kg; 3,100 mg/kg average.	Soil spread on plastic sheeting to thickness of 14 to 18 inches; One time ammonium nitrate nutrients (C:N:P ration of 200:10:1); Soil aerated twice a month; Soil moisture content	Ex situ		Total capital cost - $104,257; Estimated annual operating cost - $18,460.

				10% - 15%.			
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	USACE/DOD-financed Installation Restoration Program.
Navy Demo Camp Pendleton, CA 1991 William Sancet (619) 725-3868	Land treatment: 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 waste produced. No future maintenance required	$351/cubic yard.
Petroleum Products Terminal Al Leuscher Remediation Technologies, Concord, MA	Landfarming	Soil	TPH 1,000 ppm Level attained: 100 ppm				Soils segregated by contami- nation type- treated for 3 years (seasonal operation)
Fuel Oil Spill Foster Wheeler Joe Matthewson Santa Fe Springs,CA	Landfarming	Soil	TPH 6,000 ppm Level attained: 100 ppm				Heavy clays required addition of soil amendments 120 treatment days
Creosote John Matthews EPA RSKERL (405)436-8600	Landfarming	Soil	Pyrene 135 ppm PCP 132 ppm Levels attained: < 7.3 ppm 87 ppm				NPL - Ongoing seasonal operation
Pesticide Storage Facility	Landfarming	Soil	Pesticide 86 ppm. Level attained 5 ppm				12-inch clay liner with drainage employed - 5 months' treatment
Iowa Army Ammunition Plant, Middletown, IA 1998	Slurry phase biological treatment: J.R. Simplot P.O. Box 912 Pocatello, ID 83204 208-234-5367	Soil	TNT, RDX, HMX		Ex situ		"Field Demonstration of Multiple Bioslurry Treatment..." Remediation of Chlorinated and Recalci-trant Compounds. 1998 (p 259-264)
Former Manufac. Gas Plant (MGP) Site, NJ 1997 S.P. Pradhan. and V.J. Srivastava	Slurry phase biological treatment: Institute of Gas Technology (IGT) Des Plaines, IL	Soil	PAHs		Ex situ		A Pilot-Scale Demonstration of an Innovative Soil Remediation Process: Air Emissions Quality, J. of the AWMA, 47:6 (p 710-715) June 1997
Army Demo Joliet Army Ammunition Plant, IL 1992	Slurry phase biological treatment: 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 removed & dewatered; process water recycled	Best suited for small sites where incineration is cost-prohibitive.

Kevin Keehan (410) 671-2054							
Navy Demo Naval Weapons Station unleaded gasoline spill Seal Beach, CA Steve McDonald (310) 594-7273 Carmen Lebron (805)982-1615	Slurry phase biological treatment: unleaded gasoline spill	Soil & ground water	Aromatic hydrocarbons: 1 ppb to 4 ppm of BTEX	Three 80-litre bioreactors at 72 L/day	Site soil placed in reactor - ground water pumped through	Effluent cleaned to drinking water standards for BTEX	
EPA *SITE* Demo EPA Test & Evaluation Facility, OH 5/91 to 9/91 Ronald Lewis (513) 569-7856	Slurry phase biological treatment: Bioslurry reactor	Soils, sediments, & sludge	97% reduction in PAHs	Degradation enhanced by control of pH, temperature, oxygen, nutrients, and enriched indigenous micro-organisms	Excavation, mixing, additives, sparging		Can be used for creosote and petroleum wastes.
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 carbon adsorption & biofiltration	Mobile LST pilot system.

Sources: *Innovative Treatment Technologies: Annual Status Report (Eighth and Tenth Editions, Nov. 1996 and Feb. 2001). Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America (1st and 2nd Editions, Aug 1996 and Jun 2000).*

DOE Fernald Facility, OH 1997 Alan B. Cash 619-552-9902	Solvent extraction Terra Kleen San Diego, CA	Soil	PCBs		Ex Situ		Solvent Extraction [An EPA SITE Program document will be produced.]
EPA Removal Action Traband Warehouse PCBs, OK 2/90 to 9/90 Pat Hammack (214) 655-2270	Solvent extraction Terra-Clean, Inc.	Solids	PCBs Initial: 7,500 ppm	Solvent addition	Excavation	Treated solid; concentrated contaminant	Storage management complex.
LLNL, Livermore, CA 1997 John Bowers	Chemical Oxidation Lawrence Livermore National Laboratory Livermore	Soil	Low-Level Mixed Wastes, Solvents				Fiscal Year 1997 Demonstration of Omnivorous Non-Thermal Mixed Waste Treatment: Direct Chemical Oxidation of Organic Solids and Liquids Using Peroxydisulfate UCRL-ID-129826
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	Pesticide manufacturing use/storage. Farm equipment storage.
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 meta- phosphate 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 - solidified and replaced on-site Wastewater - permitted discharge to the sewer line Sludge - off-site disposal	This treatment system is unique in the method of generating ferrous ion for the reducing step. The wastestream passed through an electrolytic cell containing consumable steel electrodes where the ferrous ions were electrically introduced into the wastestream.
EPA Removal Action PBM Enterprises, MI 3/25/85 to 10/28/85 Ross Powers (312) 378-7661	Chemical Treatment: Neutralization with hypochlorite process Mid- American Environ- mental 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, runoff, and waste hypochlorite - treated off-site Treated chips - landfilled (Subtitle D)	Silver recovery facility.
EPA Removal Action Zhiegner Refining Company 2/93 to 6/93 Dilshad Perera	Chemical treatment ENSCO	Solid (100 lb)	Mercury initial concentration >10% mercury Final concentration of mercury in recyclable precipitate was >80%.	Added salt to precipitate the mercury	Mercury pretreatment precipitated mercury salts into mercury sulfide so that the mercury can be recovered and recycled	Residual salts containing less than 260 ppm mercury were incinerated off-site.	Precious metal recovery site.

(908) 321-4356			Less than 260 ppm if mercury in tank nonrecycled salt.				
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 scrubbed and processed before release	Water content is not an obstacle although it may cause steaming.
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 into oil, water, and clean solids	Solvent flammable -must be sealed from air.
EPA SITE Demo, Research Facility, Edison, NJ, 1992 Laurel Staley, USEPA, (513) 569-7863; Theodore Trowbridge, Dehydr-Tech Corporation (210) 887-2182	Chemical Extraction; Carver-Greenfield Process (R) for Solvent Extraction of wet, oily wastes; Dehydro- Tech Corporation	Sludge	Spent petroleum drilling fluids		Waste is first mixed with a low cost hydro-carbon solvent. Solids are centrifuged away from the solvent, followed by "desol-ventizing," an operation that evaporates residual solvent.	The resulting water product required treatment due to the presence of small amounts of light organics and solvent.	Normally, the resulting water product may be disposed of at a local publicly owned treatment works.
United Creosoting, Conroe, TX Mark Meckes, USEPA, (513) 569-7348; Chris Shallice, CF Systems Corporation/ Morrison Knudsen, (216) 523-6581	Chemical Extraction; CF Systems Corporation/ Morrison Knudsen liquified gas solvent extraction (LG-SX) technology	Soil (80,000 yd^3)	Oil, grease, and PAHs		Uses liquefied gas (such as propane) solvent		
DOE pilot-scale test, Idaho National Engineering Laboratory Robert Montgomery, EG&G Idaho, (208) 525-3937	Chemical Extraction (Separation / Chemical Extraction)	Soil	Radionuclides, metals	Approxia- mtely 30% of soil matrix was co-dissolved in order to achieve release of most of the cesium-137.	Soils are screened, classified, and placed into leaching unit with hot nitric acid.	Disposal options include solidification, calcining leachate, and storage	Test results indicated excellent removal efficiencies for cobalt-60 and chromium
SUPERFUND Remedial Action, Arrowhead Refinery Co., 1994 & 1995 Edwin Smith, USEPA, (312) 353-6571	Chemical Extraction (Solvent extraction)	Soil 7,000 yd^3	Halogenated volatiles, PCBs, PAHs, solvents, heavy metals (lead)				
Marengo, OH 1997	Solvated Electron Technology (SET™)	Soil	PCBs		Ex Situ		Solvated Electron Treatment of Chlorinated Organics |An EPA SITE Program

Carl Magnell 614-297-0365	Commodore Environmental Columbus, OH						document will be produced.]
EPA SITE Demo: Naval Air Station North Island Site 4, San Diego, CA, May to June 1994 Mark Meckes, EPA, National Risk Management Research, (513) 569-7348	Chemical Extraction Terra-Kleen Response Group, Inc	Soil	PCBs, chlorinated pesticides, PAHs, penta- chlorophenol, cresote, poly-chlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans	PCB Aroclor 1260 concen-trations were reduced from a maximum of 170 milli-grams per kilogram (mg/kg) in untreated soil to less than 2 mg/kg in treated soil. The average removal efficiency was 98.39 percent.	Uses amines (usually triethyl amine).		
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 Triethy- lamine	Excavation Screening Neutrali- zation Size Reduction Mixing	Oil - used as fuel for kiln Water - treated, discharged off-site Solids - solidified and disposed of on-site	The oil recovered from the extractions process could not be sold because of an elevated metals content. The solvent could not be recovered because of leaks in system seals. The unit required a relatively uniform material so materials handling of the sludges proved difficult in the beginning of the project. The lead-bearing solids produced by the dryer also required special handling. Finally, deterrents in the sludge hindered oil/water separation.
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 salts containing less than 260 ppm mercury were incinerated off-site	First known Superfund site where this process has been applied.
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 concen- tration of sludge in the contaminated water.	Pumping	Salts from the reaction were removed with flocculation and clarification at existing treatment plant, pH adjustment	Carbon disulfide is unstable and will be found with other contaminants in aqueous wastestream. For additional information on this project, see the Removal Close Out Report available from EPA Region III or OH Materials.
EPA & Navy Demo EPA Lab,	Chemical detoxification of chlorinated	Soil	Dioxin, herbicides, chlorinated aromatic compounds, 99.9%	Soil heated to 100-150 °C if dehydrated	Excavation, Water content assessed.	Products are not toxic nor biodegradable	Incineration cheaper in some cases.

NJ Deh Bin Chan (805) 982-4191	aromatic compounds		decontami- nation achieved				
EPA Demo Douglassville, PA 10/87 Paul R. DePercin (513) 569-7797	Chemical treatment & immobi- lization	Soil, sediments, & sludge	Organic compounds, heavy metals, oil, & grease	In/ex situ. Sediments - underwater. Batch process at 120 tons/hour.	Blending	Hardened concrete- like mass	Application Analysis Report, EPA/540/A5-89/001; Technology Evaluation Report, EPA/540/5-89/00/a
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 backfilled	Proprietary, azeotropic fluid to extract contaminant from soil.
Star Enterprise, Port Arthur, TX, March 1991 to March 1992 Mark Meckes, USEPA, (513) 569-7348; Chris Shallice, CF Systems Corporation Morrison Knudsen, (216) 523-6581	Chemical Extraction; CF Systems Corporation Morrison Knudsen liquified gas solvent extraction (LG-SX) technology	Sludge	K- and F- wastes, PCBs		Uses liquefied gas (such as propane) solvent	Following heavy metals fixation, the treated solids were disposed of in a Class I landfill	
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 waste water	PCB 300-2,500 ppm 90-98% removal	Phase separation with solvent, solvent recovery	Tray tower for water; extractor/ decantors for solids and semi-solids	Heavy metal fixation, then Class I landfill	Applicable to VOCs, SVOCs, PAHs, PCBs, PCP, and dioxins.
EPA Demo Coleman-Evans Site, FL Norma Lewis (513) 569-7665	Catalytic ozone oxidation with soil washing	Soil, sludge, & ground water	Organics - up to 20,000 ppm	Soil washing enhanced by ultrasound	Soil particles greater than 1 inch are crushed	Oxidation of wastewater, carbon for off-gas	Excalibur Technology. $92 to $170/m3 ($70- $130/yd3)
EPA Remedial Action Wide Beach Development, NY 9/90 to 9/91 Herb King (212) 264-1129	Dehaloge- nation/ APEG dechlorination Soil Tech Denver, CO	Soil (40,000 yd^3)	Criteria: PCBs (Aroclor 1254)- <10 ppm (1 composite sample/day) Input: 10 to 120 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 on-site	If on-site disposal is planned, perform tests of the treated material appropriate to intended use. For further information on this dechlorination project, see the Demonstration Test Report produced by EPA, Region II.
PWC Guam Jess Lizama	Dehalogenation	Soil	2,500 ppm PCB average Levels attained: <10 ppm				
Montana Pole Butte, MT	Dehalo- genation	Soil	Dioxin, Furans/Oil <84 ppm Attained: <1 ppb				

Economy Products Omaha, NE	Dehalo- genation	Soil	TCDD, 2, 4-D, 2, 4, 5-T (liquid) Beginning levels: 1.3 ppm 17,800 ppm 2,800 ppm Levels attained: Non-detect 334 ppm 55 ppm				
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 of residuals (without dioxin contamination) at treatment, storage, and disposal facility	Waste management facility warehouse.
Los Alamos National Laboratory (LANL) Coyne Prenger LANL	Magnetic Separation	Soil					
DOE Demo INEL, ID 1992 Robert Montgomery (208) 525-3937	Physical separation/ chemical extraction	Sediments	Radionuclides & metals	Contami- nants removed from leachate by ion exchange, reverse osmosis, precipitation, or evaporation	Screening, segregation, leaching with hot nitric acid	Solidification, calcining leachate, or storage	Difficulty removing Cesium-137. Cost: $1,000/yd^3
EPA Demo Iron Mountain Mine Site, CA 1990 to 1991 S. Jackson Hubbard (513) 569-7507	Separation: 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 precipi- tation, filtration, concentrated stream dewatering	Filter cakes 40-60% solids, water recycled	EXXFLOW and EXXPRESS fabric microfilter and filter press.
Hunter's Point Shipyard, San Francisco, CA 1998 Rob Stephenson 604-273-0311	Soil Washing ChemTech Analysis, Inc. Klohn-Crippen Consultants Ltd. Richmond, BC, Canada	Soil	Cu, Cr, Pb, Z		Ex situ		"Soil Washing System Employs Aggressive Conditions to Handle Organics. Inorganics," HazTech News, 13:6, 9 Apr 1998
DOE Mound Facility, Miamisburg, OH 1997 Michael Dunn	Soil Washing Selective Environmental Technologies, Inc. (Selentec) Atlanta, GA Michael Dunn	Soil	Pu, Thorium		Ex situ		"Mound Pilots Process That Washes Soil Clean," New Directions, Jun/Jul 1997 (p 1 & 6)
Ft. Polk, LA US Army Environmental Center Lisa Miller (800) USA-EVHL	Soil Washing featuring physical separation and acid leaching for the recovery and recycle of lead from small arm range soil.	Soil	Lead: 3500 mg/kg	After treatment: 200 mg/kg total lead 2 mg/L TCLP			$170 per ton for 10,000 ton site

Naval Facilities Engineering Service Center Barbara Nelson							
Twin Cities AAP New Brighton, MN Michael D. Royer (908) 321-6633	Soil Washing featuring gravity separation, particle size classification, metal leaching, and lead recovery	Soil	Targets for background remediation: Cr, Cu, Hg, and Ni. Some batches reached state remediation goals.				
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 separator, filter, and bioreactor	Self-contained mobile soil washing unit.
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 were left at the facility Wastewater discharged to confined disposal facility	Forced cold-weather shutdown is a limitation.
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 & debris, recycle water, off-gas from organics & concentrated contami- nants	Selective extraction/ dissolution.
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 and off-site disposal	Plant is being optimized for further demonstration.
EPA Demo Toronto Port Industrial District, Canada 1991 Teri Richardson (513) 569-7949	Soil washing/ Soil recycling	Soils	Organics and Inorganics	Inorganics extracted; organics extracted and biodegraded.	Soil washing, metal dissolution, chemical hydrolysis with biodegra- dation	Metals recovered in pure form. Reusable fill	90% reduction in PAHs.
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 metals landfilled	Contaminated to depth of 18 inches.
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 required	Commercially available.
EPA Demo Alaska Battery Enterprises	Soil washing plant	Soil	Heavy metals, radionuclides	Rate dependent on percentage of soil fines - up to 20 tons/hour	Deaggio- meration, density separation, and material sizing	Concentrated contaminant con- tainerized, liquid recirculated clean	Process modified to accommodate unexpectedly high levels of lead and

Superfund Site, AK 1992 Hugh Masters (908) 321-6678						soil	battery casings.
EPA Demo MacGillis & Gibbs Superfund Site, MN 1989 Mary Stinson (908) 321-6683	Soil washing system (volume reduction), process water treated in a bio-reactor, fines treated in a slurry bioreactor.	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 treated in fixed film bioreactor	Patented water based volume reduction process.
EPA Demo Pensacola, FL 11/92 Teri Richardson (513) 569-7949	Soil washing: Volume reduction unit	Soils	Organics - creosote, PCP, pesticides, PAHs, VOCs, SVOCs, metals	Up to 100 lb/hour	Particle separation and solubilization	Concentrated contaminant	Pilot-scale mobile soil washing unit.
Toronto Port Industrial Dist. Ontario, Canada Dennis Lang (416) 863-2047	Soil washing (volume reduction), metal dissolution, and chemical hydrolysis with biodegradation (organics)	Soil	52 ppm Naphthalene; 10 ppm benzo(a)-pyrene Levels attained: <5ppm; 2.6ppm				
Escambia Wood Treating Company Superfund Site, Pensacola, FL Terri Richardson EPA RREL	Soil Washing featuring particle size classification and surfactant addition	Soil	From 550-1,700 ppm PAHs 48-210 ppm PCP to 45 ppm PAHs 3 ppm PCPs				$151/metric ton ($137/ton) (projected)
Installation Restoration (IR) Site 4, NAS Northern Island, San Diego, CA	Terra-Kleen Soil Washing combined with SVE	Soil	Reduced PCB levels in soil from 144 mg/kg to 1.7 mg/kg on average				$500,000 for the field-scale treatability demonstration .
Escambia Wood Treating Company Superfund Site, Pensacola, FL Terri Richardson EPA RREL	Soil Washing featuring particle size classification and surfactant addition	Soil	From 550-1,700 ppm PAHs 48-210 ppm PCP to 45 ppm PAHs 3 ppm PCPs				$151/metric ton ($137/ton) (projected)
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 of soil vapors through 30-ft stack	For further information on this application, see the *Applications Analysis Report for the Terra Vac In Situ Vacuum Extraction System* (EPA/540/A5-89/003).
EPA Removal Action Basket Creek Surface Impoundment, GA 11/92 to 2/93 Don Rigger	Vacuum extraction of soil pile with horizontal wells (ex situ) OHMaterials, Inc.	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	Vacuum pressure monitored. 1,300-CFM/ manifold. 3 manifolds 6 to 7 wells/ manifolds	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	Residual soils and rejects from screening met TCLP limits and were disposed of as nonhazardous in RCRA Subtitle D landfill. Incinerated 70,000 lb of VOCs.	$2M total costs. Permeability in situ soil was not good at first. Excavation and ex situ treatment improved permeability. Shouldn't rule out if can't be done in situ.

(404) 347-3931			PCE - 0.7 mg/L TCLP All VOCs met TCLP limits		extraction wells. Recovered VOCs with duct work and fan. Vapors incinerated.		
Installation Restoration (IR) Site 11, NAS Northern Island, San Diego, CA	Terra Vac pilot SVE/ Air Sparging/ Catalytic Oxidation System	Soil	Up to 250 pounds (33 gallons) per day of VOCs was effectively removed from the vadose zone and subsequently destroyed.				
DOE Demo Lawrence Livermore National Laboratory, CA 1991 Jesse L. Yow, Jr. (510) 422-3521	Solar Detoxification	Ground water	VOCs	Exposed to sunlight & nontoxic catalyst (TiO_2)	Pumping, solar detox, pH adjustment, catalyst addition	Catalyst filtered out and water sent for secondary treatment	Salts in ground water reduce efficiency.
Tyndall Air Force Base	Solar Detoxification	Ground water	Jet fuel	Exposed to sunlight & nontoxic catalyst (TiO_2)	Pumping, solar detox, pH adjustment, catalyst addition	Catalyst filtered out and water sent for secondary treatment	Salts in ground water reduce efficiency.
Savannah River Site Incinerator, Aiken, SC 1998 D. Singh	Solidification/ stabilization Argonne National Laboratory Argonne, IL	Soil,	Radioactive Ash		Ex situ		Phosphate Bonded Solidification of Radioactive Incinerator Wastes WSRC-MS-99-00314
Midvale Slag Superfund Site, Midvale, UT 1997 Robert Kuhn 914-623-2333	Solidification/ stabilization Solucorp Saddle Brook,	Soil,	As, Cd, Pb		Ex situ		Molecular Bonding System®, Solucorp Industries Ltd. EPA 540-R-97-507
ORNL, Oak Ridge, TN 1997 Catherine Mattus 423-574-6793 h6z@ornl.gov	Solidification/ stabilization Oak Ridge National Laboratory	Soil,	Mixed Wastes: Cd, Pb, Radionulides		Ex situ		Demonstration of Mixed Waste Debris Macroencap-sulation Using Sulfur Polymer Cement [fact sheet]
Rocky Mountain Arsenal 1997 Richard W. McManus 214-393-6965	Solidification/ stabilization SOUND/epic Anchorage, AK	Soil,	Na, Cu, K, Nitrate, Pesticides		Ex situ		Dispersion by Chemical Reaction Testing of Rocky Mountain Arsenal Basin F Waste Soils CRREL Special Report 97-3
EPA *SITE* Demo Robins AFB, Macon, GA 8/91 Terry Lyons	Solidification/ stabilization	Soil, sludge, liquid	Organics and inorganics	Uses proprietary bonding agents	Large debris must be prescreened	Non-leaching high-strength monolith	Process can be applied in situ.

(513) 569-7589							
EPA *SITE* Demo Selma Pressure Treating Selma, CA 11/90 Edward Bates (513) 569-7774	Solidification/ stabilization with silicate compounds	Ground water, soil, sludge	Organics and inorganics	Silicate compounds	Pretreatment separation of coarse and fine materials	PCP leachate concen- trations reduced up to 96%. As, Cr, and Cu immobilized.	Applied to a wide variety of hazardous soils, sludges, and wastewaters.
EPA *SITE* Demo Portable Equip. Salvage Co. Clackamas, OR 9/89 Edwin Barth (513) 569-7669	Chemfix process - solidification/ stabilization	Soil & Sludge	Solid waste	Uses soluble silicates and silicate- settling agents	Blend waste with dry alumina, calcium, and silica-based reagents	Produces friable solids. Cu and Pb TCLP extracts were reduced 94-99%	Applicable to electroplating wastes, electric arc furnace dust.
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 debris (wood and metal scrap) is produced	Estimated cost: $85/ton of waste.
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 metals in untreated waste were immobilized. VOCs not detected in treated waste.	pH of untreated waste was 3.4 to 7.9. Treated waste had pH 11.7 to 12.
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 reduced from 720 to 0.9 ppm Pb, 7 to 0.2 ppm Cu, 4.1 to 0.2 ppm Zn	Treated soil is returned to its original location. Estimated cost $490/ton.
DOI Demo Salt Lake City Research Center K.S. Gritton (801) 584-4170	Vitrification: 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 of arsenic sulfide leaves a dense, non-reactive, glass-like material	Emphasis is on recovery of metals, which are presently discarded.
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 and metallic phase	Slag is 3 times more dense; metallic phase is 10 times more dense.
EPA & DOE Demo Component Development & Integration Facility, MT 1991	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 laden vapor stream and metals laden vitrified mass.	$750- $1,900/ton.

Laurel Staley (513) 569-7863 R.C. Eschenback (707) 462-6522							
Davis-Monthan AFB. Brad Jones (402) 221-4488	solidification/ stabilization	Dross and dross contaminated soil	Cd, Cr, and Pb	Dross and dross contaminated soil was mixed with 10% cement and 5% lime in pug mill.		Passed TCLP for all contaminants.	Cost: $100 per cubic yard.
Installation Restoration (IR) Site 2, NAS Northern Island, San Diego, CA	Western Product Recovery Group's (WPRG) Chemical Coordinate Bonding and Adsorption (CCBA) technology	Soil	Up to 250 pounds (33 gallons) per day of VOCs was effectively removed from the vadose zone and subsequently destroyed.	Contaminated soil is heated to a high temperature and mixed with clay. The clay's silicon matrix reacts with the metals to form metal silicates, which chemically fix the metals to the final treatment product.		Treated soil can be reused as on-site backfill or recycled as landscaping material, road base material, or aggregate for concrete material.	

Sources: *Innovative Treatment Technologies: Annual Status Report (Eighth and Tenth Editions, Nov. 1996 and Feb. 2001). Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America (1st and 2nd Editions, Aug 1996 and Jun 2000).*

EPA Demo Hamilton Harbor, Canada 1992 Gordon Evans (513) 569-7684	Thermal gas phase reduction	Soil, sludge, liquids, & gases	Hydrocarbons PCBs, PAHs, chlorophenols, pesticides	850 °C or higher - 25 tons/day	Reduction of hydrocarbons in presence of hydrogen	Offgas stream	Mobile reactor.
HWAAP Hawthorne, NV Louis Kanaras, USAEC (410) 612-2054	Hot Gas Decontamination	Soil	99.99% removal of TNT				Successful pilot-scale demonstration
EPA Demo Babcock & Wilcox, OH Laurel Staley (513) 569-7863	Cyclone Furnace	Soil	Organics & metals	820 °F	Swirling action mixes air & fuel	Final product resembles volcanic glass (similar to ISV's product)	$528/ton of soil.
EPA Demo Ogden's Research Facility San Diego, CA Douglas Grosse (513) 569-7844	Circulating bed combustor (CBC)	Soil, sludge, liquids, solids, slurry	Halogenated and nonhalogenated organic compounds, PCBs, dioxins	16-inch diameter CBC, 1,450-1,600 °F, waste feed <1 inch	Highly turbulent combustion zone. Mixing wastes Limestone added to neutralize acid gases	DRE value of 99.99% for principal organics. Treated ash disposal	Controlled sulfur oxide emissions by adding limestone.
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	Nonleachable slag, disposal in landfill	Secondary lead smelter soda slag processed for $932/ton. 1 to 3 tons/hour cap.
EPA *SITE* Demos (1) Tampa, FL, 8/87 (2) Rose Township/ Demode Road Superfund Site, MI, 11/87 John F. Martin (513) 569-7696	Incineration: Infrared thermal destruction	Soil, sediment, liquid organic wastes mixed with sand or soil	Organics	Infrared radiant heat of up to 1,850 °F	May need to restrict chloride levels in the feed	PCBs consistently meet TSCA guidance 2 ppm in ash	PCB DRE was greater than 99.99% based on detection limits. RCRA standards for particulate emissions questionable.
Peak Oil Site Tampa, FL Howard O. Wall EPA RREL (513) 569-7691	Full scale: electric infrared mobile incineration unit	Soil	Oil sludge (PCBs and lead)				$180 to $800/metric ton ($164- $730/ton)
Savanna AD Savanna, IL Michael G. Cosmos (610) 701-7423	Full scale transportable incineration system	75,000 tons of soil	1,000 ppm TNT Levels attained: < 1 ppm				$180/metric ton ($173/ton) inclusive
Lauder Salvage Yard Beardstown, IL Michael G. Cosmos (610) 701-7423	Full scale transportable incineration system	Soil	From 12,000 ppm PCBs to < 1 ppm				$200/metric ton ($180/ton)
DOE Demo Energy Technology Engineering Center, ORNL, LANL Lawnie H. Taylor (301) 903-8119	Pyrolysis: Molten salt oxidation process	Liquids & solids	Radionuclides organics, oils, graphite, chemical warfare agents, & explosives	800-1,000 °C Typical residence time is 2 seconds	Waste passed through a sparged bed of turbulent molten salt.	Off-gas filtered before release	$500/ton.

HT-V TDI Thermal Dynamics	Mobile thermal desorption unit with pyrolytic mode	Soil	Dioxin 99.99% removal				
Deutsche Babcock Anlagen AG	Pyrolysis - Desorb and combust volatiles	Soil	Polycyclic aromatics, 99.77% removal				
Wide Beach Superfund Site NY SoilTech, Inc.	Pyrolysis - Anaerobic thermal processor (ATP), indirectly heated rotary kiln	Soil	From 5,000 ppm PCB to < 2 ppm				$290/metric ton ($265/ton)
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 - solidified and disposed of on-site Vapors - air carbon capture	Industrial landfill.
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 vocOutput: <1 ppm total vocs	Batch process	Excavation Screening	Carbon from air pollution control unit regenerated off-site	For more information on this project, see the close out report available from EPA Region I.
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 soil and sediment stored in on-site containment cells. Wastewater discharged to POTW.	Reduced PCB levels much more than expected.
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 (total) Input: 500 to 3,000 ppm (total VOCs) Output: <0.25 ppm (total vocs)	Continuous operation 40 tons/hour 450 to 500 °F Moisture content before treatment - 5 to 25% moisture Additives - dry soil (to reduce moisture content)	Excavation Screening Mixing Dewatering	Residuals from air pollution control - disposed of off-site Wastewater - treated on-site	The waste feed size limitation for the equipment, (1.875 inches), was an important consideration. More information is in the RA report available from EPA Region I.
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 was backfilled into the excavated areas on-site. Soil that did not meet the targets was retreated. Wastewater was treated on-site through carbon filters.	Total cost approximately $250,000.
EPA Demo ReSolve, Inc., Superfund Site, MA	X*TRAX™ thermal desorption	Soil	VOCs, SVOCs, & PCBs	Heated rotary dryer, 750-950 °F	Separation technique	Negligible organic air emission. No PCBs detected in vent gases	Metal concentrations and soil physical properties not altered by system.

1992 Paul DePercin (513) 569-7797 Carl Palmer (803) 646-2413			Average PCB removal efficiency: 99%				
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 contaminant stream through cyclone, baghouse, scrubber, and carbon.	No dioxins or furans created.
EPA Demo Niagara- Mohawk Power Co., NY 6/91 Ronald Lewis (513) 569-7856	High Temperature Thermal Processor	Solids & sludges	VOCs, SVOCs, & PCBs	850 °F, 150 °F for safe handling	Rotation of screws moves material	Controlled by an indirect condensing system & activated carbon beds	Not suitable for heavy metals. Prescreening necessary to obtain particles <1 inch.
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 exhaust air and liquid with GAC. Does not generate dioxins or furans.	Efficient performance with no down time.
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 McLaren/Hart Environmental Engineering (704)587-0003	Soil	VOCs (chlorinated solvents & fuels); 99.9% destruction	Up to 650 °F	Churning - Holo-Flite screw thermal processor	Gaseous effluent with concentrated contaminants.	Nitrogen may be used if contaminants are explosive.
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 (LT^{360})	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 phases are disposed of off-site	All cleanup goals met when soil above 215 °F.
EPA *SITE* Demo EPA Combustion Research Facility, Jefferson, AK 11/87 to 1/88	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 POHCs >99.99%	Not suitable for aqueous, RCRA heavy metal, or inorganic wastes.

Laurel Staley (513)569-7863							
Alaskan Battery Enterprises Superfund Site, Fairbanks, AK Hugh Masters EPA RREL	Thermal Desorption featuring gravity separation and particle size classification	Soil	From 2,280- 10,374 ppm lead to 15-2,541 ppm lead				$182/metric ton ($165/ton)
Escambia Wood Treating Company Superfund Site, Pensacola, FL Terri Richardson EPA RREL	Thermal Desorption featuring particle size classification and surfactant addition.	Soil	From 550- 1,700 ppm PAHs, 48-210 ppm PCP, to 45 ppm PAHs, 3 ppm PCPs				$151/metric ton ($137/ton) (projected)
Pristine, Inc., Reading, OH Tom Alcamo U.S. EPA (312)886-7278	Thermal Desorption	Soils with a wide range of pH and moisture conditions. 11,500 tons of soil	VOCs up to 0.14 ppm; SVOCs up to 130 ppm; 4,4-DDT ranging from 0.11 to 8.2 ppm; Lead ranging from 26 to 1,100 >99.99% Destruction and Removal Efficiencies for PAHs and pesticides.	Treated at 1,009.9 to 1,034.1°F.			
T H Agriculture & Nutrition Company Superfund Site, Albany, GA R. Donald Rigger (404)347-3931	Thermal desorption	42,000 tons of soil	Organochlorine (OLC) pesticides Concentration of OLC pesticides: >1,000 mg/kg >98% average removal efficiencies	Treated at 833 to 1,080°F for 15 minutes.			Treatment cost: $849,996; Before-treatment cost: $252,582. $200 per ton or $340 per cubic yard soil treated.
Anderson Development Company Superfund Site, Adrian, MI Jim Hahnenburg (312)353-4213	Full-scale treatment using a thermal auger system with hollow-screw conveyors.	5,100 tons of soil	MBOCA, VOCs, PAHs and heavy metals	treated at 500-530° F for 90 minutes.			
McKin Company Superfund Site, Gray, ME Sheila Eckman (617)573-5784	Thermal Desorption	11,500 cubic yards of soil	3,310 mg/kg of TCE, 130 mg/kg of Ethylbenzene, 35 mg/kg of Toluene. Treated to <0.1 mg/kg of TCE, <1 mg/kg of other VOCs	Treated at 250-400°F for 6 minutes.			Total cost: $2,900,000

Sources: *Innovative Treatment Technologies: Annual Status Report (Eighth and Tenth Editions, Nov. 1996 and Feb. 2001). Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America (1st and 2nd Editions, Aug 1996 and Jun 2000).*

AFCEE action, Fairchild AFB, WA Gil Dominguez (210) 536-4228	Landfill Cap	Soil		Pump and treat system pulls TCE from ground water below landfill			
DOE Oak Ridge, TN facility Oak Ridge Centers for Manufacturing Technology	Landfill Cap	Soil		The method developed involved contouring the top surface of each waste area into a berm shape. Two feet of clay was highly compacted to a permeability of $1x10^{-7}$ cm/s. The clay was then covered with 30-mil polyvinyl chloride (PVC) welded into one piece. A drain net with a filter on top was then placed on top of the PVC in lieu of the normal 1 ft of sand to allow the water to drain as much as possible before reaching the PVC. Two feet of earth was placed on top to provide for green cover growth (engineered caps).			
Lawrence Livermore National Laboratory, Site 300, Coast Ranges, CA, 1992 Michael J. Taffet	Landfill Caps	Soil		8 foot thick RCRA capwith upgradient interfacial flow diversion system			
DOE Demo, Lee Acres landfill, Farmington, NM Ray Finley (505) 848-0776	Landfill Caps	Soil (33,000 sq ft)		Design includes laboratory characteri- zation of candidate soils, numerical modeling, performance predictions using advanced unsaturated flow tools used in previous Sandia National Laboratories (SNL) capillary barrier research, and specification and installation of in situ instrumen-tation to monitor the performance of the deployment			
DOE Demon-stration, Sandia National Laboratories Steve Dwyer (505) 844-0595	Water Harvesting Vegetative Cover	Soil (Landfill)		In situ instrumen-tation	None		
MCAS Kaneohe Bay	Water Harvesting Vegetative Cover	Soil (landfill)		All plots are equipped with instruments to	Periodic measurements of species		In FY94.

John Kornuc, NFESC, (805) 982-1615				monitor daily precipitation, percolation, runoff and sediment yield, and soil moisture in order to compute a water balance for each design. Evapo-transpiration is estimated. Automated data acquisition systems are used for most of the measurement variables.	composition, biomass, canopy cover, ground cover, and leaf area index will also be taken of the vegetation cover on each plot.		

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Bendix Corp./Allied Automotive St. Joseph, MI	Cometabolic treatment	Ground water	TCE, DCE, DCA,VOCs				CERCLA Lead Predesign - anaerobic cycle to treat TCE
DOE Classified Burial Ground, Oak Ridge K-25 Site Rashalee Levine, U.S. DOE (301) 903-7920	Co-metabolic Treatment	Ground water, Seep	TCE, Organics	Two different reactors where micro- organisms were grown to form biofilms over the surfaces within the packed-bed. Methano- trophic and pseudomonas micro- organisms used.	Ex-situ bioreactors.	Generation of chloride ions.	may also have some effectiveness in treating fuels and pesticides. Also, treatability is highly dependent upon the biodegrada- bility of the contaminants. 1994
Naval Communi-cation Station, Scotland 2/85 to 10/85 (U.S. Navy) Deh Bin Chan (805) 982-4191	Bioremediation In situ soil, in situ ground water	Soil, ground water Soil quantity approxi-mately 800 m^2 in area, depth unknown	TPH (No. 2 diesel fuel)	Micro- organisms function best between 20 °C and 35 °C.	Runoff water collected in a trench	None	The contaminated area had considerable slope, and the contaminated soil was a thin layer over a relatively impermeable rock substrate.
DOE Demo Savannah River Site, SC Nate Ellis (803) 952-4846 Brian Loony (803) 952-5181	Aerobic Biodegradation	Ground water	TCE, PCE @ 1,000 ppb; 90% removal efficiency	Aquifers must be homogenous	Methano- trophic fluidized bed or trickle filter bioreactor	<1 lb/day produced	Water high in copper may inhibit the process - Cost about $0.50/gallon.
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 micro- aerophilic bacteria and nutrients. Hardy bacteria can treat contaminants over a wide temperature range.	Only degradation products are CO_2 & H_2O	Failed to meet cleanup standards for BTEX.
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	None	High copper concentration can inhibit the process. $150K cap
DOE Demo Hanford Site, WA Thomas M. Brouns (509) 376-7855 Rodney S. Skeen (509) 376-6371	Biological treatment	Ground water	Nitrate reduced by 99% from 400 ppm. CCl_4 reduced by 93% from 200 ppb	In situ	Provides ultimate destruction of contaminant	No spent activated carbon need be disposed	Requires half the time for remediation, very cost-effective.
NAS Fallon, NV 1992 U.S. Navy, Public Works Department (702) 426-2772	Bioventing	Ground water	Hydrocarbons				Airfield
Air Force & DOE Demo Tinker AFB, OK 1989 Alison Thomas (904) 283-6028	In situ & above-ground biological treatment of trichloro- ethylene	Ground water	80% destruction of TCE	In situ or in a bioreactor	Bioreactor design uses methane degrading bacteria to cometabolize TCE	TCE destroyed	Alternative system using altered micro- organisms is being tested at Hauscomb AFB, MA.

Air Force Demo Eglin, AFB, FL 1/94-10/94 Alison Thomas (904) 283-6028	In situ anaerobic biodegradation	Ground water	Jet fuel (toluene, ethylbenzene, xylene)	In situ; nitrate is added to serve as electron acceptor		Benzene is recalcitrant under strict anaerobic conditions	Cost $160-$230/gallon fuel removed.
Air Force Demo Kelly AFB, TX & Eglin AFB, FL Catherine M. Vogel (904) 283-6036	In situ biodegradation	Soil & ground water	Hydrocarbons - fuels, fuel oils, & nonhalogenated solvents	In situ	Nutrients introduced into aquifer through irrigation wells - some precipitation problems occurred		Site characterization necessary to determine soil/chemical compatibility.
DOI Demo Picatinny Arsenal, NJ Thomas E. Imbrigiotta (609) 771-3900	In situ biodegradation	Ground water	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 anaerobically broken down into DCE then VC and finally to ethylene, which will breakdown and volatilize	Use of surfactants to enhance desorption from aquifer sediments is being studied.
DOI Demo Defense Fuel Supply Point, SC Late summer 1993 Dr. Don A. Vroblesky (803) 750-6115	In situ enhanced bioremediation	Ground water	Jet fuel	In situ	Uncontami- nated groundwater is amended with nutrients and pumped into a series of infiltration galleries	Ground water extracted and discharged to treatment facility	Microbes that degrade contamination occur naturally in contaminated groundwater.
DOE Tech Demo (USGS) Galloway Township, NJ 1988 Herbert T. Buxton (609) 771-3900	In situ vapor extraction and bioventing design	Soil & ground water	Gasoline	AIRFLOW - an adaption of the USGS groundwater flow simulator	MODFLOW to perform airflow simulations		
Stalworth Timber Beatrice, AL Jason Darby (404)347-3433	In situ enhanced bioremediation	Ground water		In situ	Addition of O_2 potassium nitrate, potassium phosphate, and molasses		
Park City Park City, KS John Wilson (405)332-8800	In situ enhanced bioremediation	Ground water	Petro, benzene Benzene treated to 5 ppb	In situ	Ammonium chloride and nitrate addition		$650K expected total
Mayville Fire Department Mayville, MI Jon Mayes (517)684-9141	In situ enhanced bioremediation	Ground water	BTEX (1/800/70/300 ppb)	In situ	Treatment with indigenous organisms		
Dover AFB Dover, DE Milton Beck (302)677-6845	In situ enhanced bioremediation Oxygen enhancement with Air Sparging and Bioventing	Ground water (230,000 m3)	PAHs, TCE metals, solvents	In situ			Total full scale $1.2M
French Limited Crosby, TX Judith Black	In situ enhanced bioremediation CERCLA Lead air	Ground water	PCB, As, and petroleum Treated to MCLs	In situ			Total $90M

(214)655-6735	sparge, O_2, and nutrient addition						
Knispel Construction Site Horseheads, NJ Frank Peduto (518)457-2462	In situ enhanced bioremediation UST Lead - H_2O_2 and nutrient addition	Ground water	Petroleum hydrocarbons treated to 5 ppb	In situ			O&M $250K
Orkin Facility Fort Pierce, FL Joe Malinowski (404) 888-2895/TD>	In situ enhanced bioremediation H_2O_2 and nutrient addition	Ground water	Chlordane and heptachlor	In situ			TSCA Lead
Farfield Coal & Gas Farfield, IA Steve Jones (913) 551-7755	In situ enhanced bioremediation H_2O_2 and nitrate injection	Ground water	Coal tar BTEX, PAHs Treated to 1 ppb benzene, 200 ppt cPAHs	In situ			Total $1.6M
Natural Gas Pipeline Compressor Station, VA 1998 Robert Legrand 512-454-4797	In situ enhanced bioremediation	Ground water	TCE, PCE	In situ			"Full-Scale In Situ Cometabolic Bioremediation at a Pipeline Site," Engineered Approaches for In Situ Bioremediation of Chlorinated Solvent Contam-ination. 1999 (p 113-119)
Watertown, MA 1998 Maureen A. Dooley Wakefield, MA 781-245-6606 Stephen S. Koenigsberg 949-366-8000	In situ enhanced bioremediation Harding Lawson Assoc. Regenesis San Juan Capistrano, CA	Ground water	TCE, PCE	In situ			"Passively Enhanced In Situ Biodegradation of Chlorinated Solvents," Engineered Approaches for In Situ Bioremediation of Chlorinated Solvent Contamination. 1999 (p 121-127)
Manufacturing Facility/ Superfund Site 1998 James J. Reid 614-764-2310	In situ enhanced bioremediation ARCADIS Geraghty & Miller Dublin, OH	Ground water	TCE, PCE, cis-1,2-DCE	In situ			"Pilot Study for Enhanced Biodegradation of Chlorinated VOCs," Engineered Approaches for In Situ Bioremediation of Chlorinated Solvent Contam-ination. 1999 (p 135-140)
Columbia County Landfill, GA 1997 James Ullery 706-722-3490	Biodegradation Southeastern Technology Center (STC)	Ground water	Organics & Metals	In situ			"Southeastern Technology Center Tests Aerobic System..." Tech Trends, July 1997
DOE K-25 Site 1994 U.S. Department of Energy (301) 903-	Biodegradation	Ground water	TCE, Organics				Demons- tration of Cometabolic Techniques

7920							
Libby Ground Water Superfund Site 1995 National Risk Management Research Laboratory (513) 569-7949	Biodegradation	Ground water	PAHs, PCP				Wood Preserving Facilities
Public Service Company of Colorado, CO 1992 U.S. EPA Region 8	Bioremediation	Ground water	BTEX				Electric Utility Site
Kennedy Space Center, FL Lawrence Livermore National Laboratory (510) 423-3118	Bioremediation	Ground water	TCE				
CSX McCormick Derailment Site, SC Steve Spurlin (404) 347-3931	Enhanced Biodegradation - Anaerobic biodegradation	Ground water	BTEX	Solubilization of nitrate.	In situ circulation.	Residual wastewater sent off-site for treatment.	Derailment, 130K gallon spill. Depth of treatment approxi- mately 2-12 ft. Operational; projected completion summer 1997.
Automotive St. Joseph, MI Bendix Corp./Allied	Enhanced Biodegradation - Anaerobic biodegradation	Ground water	TCE, DCE, DCA, VC	CERCLA Lead Predesign - anaerobic cycle to treat TCE. Nitrate serves as electron acceptor.	Solubilized nitrate is circulated throughout groundwater contami- nation zones to provide electron acceptors for biological activity and enhance the rate of degradation of organic contaminants.	In situ biodegradation.	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 micro- aerophilic conditions.
Park City Site, Park City, KS John Wilson (405) 332-8800	Enhanced Biodegradation - Anaerobic biodegradation	Ground water	Petro, Benzene	Nitrate and ammonium chloride are circulated throughout the contamination zones.	Solubilization of nitrate and ammonium chloride.	In situ biodegradation.	Benzene - 5 ppb. Expected cost - $650K. 1992
Burlington Northern, Somers Plant, MT Jim Harris (406) 449-5720	Enhanced Biodegradation - in situ addition of nutrients and oxygen	Ground water	Phenols, Creosote		In situ addition	Intrinsic biodegradation	Wood Preserving. Operational since May 1994; completion date unknown
U.S. AEC site: Fort Wainwright, Alaska Michael Lilly (mrlilly@ usgs.gov)	Natural Attenuation	Active groundwater/ surface water system	Chlorinated hydrocarbons	Regular sampling and sample analysis.		In situ contamination degradation	Still under investigation; results will be published. Site remains active.
Columbus AFB, MS Tom deVenoge, USAF Tyndall AFB, FL (904)283-6205	Natural Attenuation	Ground water	Hydrocarbons	In situ	Controlled releases of various hydrocarbons were extensively monitored and modeled over time		

Aberdeen, MD	Organic Pumps, Phyto-volatilization, Rhizofiltration	Ground water	Trichloro- ethylene, Trichloroethane				Plants used: Poplar Trees
Ogden, UT	Phyto- extraction	Ground water, Soil	Petroleum Hydrocarbons				Plants used: Alfalfa, Poplar Juniper, Fescue
Calhoun Park Area (Operable Unit 1)	Phyto- remediation	Ground water	Benzene Toluene Ethylbenzene Xylene	Hybrid Poplar Tress	Operational		
Tibbetts Road	Phyto- remediation	Groundwater	Trichloroethene	Poplar Trees	Pre-design		
Naval Undersea Warfare Station (4 Areas, Operable Unit 1)	Phyto- remediation	Groundwater	1,1,1-Trichloroethane	Poplar Trees	Operational		
Aberdeen Pesticide Dumps (Operable Unit 5)	Phyto- remediation	Groundwater	Benzenehexachloride (NR) Dieldrin (NR) Hexachlorohexane (NR)	Hybrid Poplar Trees	Pre-design		
U.S Air Force Facility, Fort Worth, TX Steve Rock (513) 569-7149	Phyto- remediation	Ground water	Trichloro- ethylene (TCE)	Eastern cottonwood trees. Depth to ground water is 6 to 10 feet	Evaluating difference between planting seedlings (whips) and older trees (1 to 1-inch caliper). Rows planted perpendicular to plume. Up gradient controls and 20 monitoring wells up- and down-gradient have been installed.		Older trees cost substantially more, but may send their roots to the water table more quickly
Milan Army Ammunition Plant, TN Darlene Bader, U.S. Army Environmental Center, (410) 612-6861	Phyto- remediation	Ground water	Explosives (TNT, RDX, HMX, DNT)	Constructed wetlands	Phase I started 1995		Plants used: Duckweed, Parrot Feather
DOE, Bear Creek, Oak Ridge National Laboratory, TN Manufacturing Technology Information Service	Phyto- remediation Phytotech, SAIC	Ground water	Uranium	Sunflower plants	Grown hydro-ponically in small greenhouse		

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DOE Mound Facility, Miamisburg, OH 1997 James Johnson 937-847-5234 james.o.johnson@em.doe.gov	Air Sparging DOE Ohio Sites Technology Coordination Group (STCG) Miamisburg	Ground water	VOCs	In situ		
DOE Demo Hanford Reservation, WA Steve Stein (206) 528-3340	Air Sparging	Ground water	VOCs	In situ - In well air stripping	Surfactants or catalysts added if needed	R st u
Amoco Petroleum Pipeline Constantine, MI	Air Sparging, Dual Phase Extraction and GAC to recover free product and treat ground water.	775 million gallons of ground water	300,000 to 2 million gallons of gasoline, fuel oil, and kerosene	In situ air sparging was subsequently added to treat the saturated zone. 4 extraction wells and 30 air sparging wells were installed. 2 GAC vessels in series	118,000 gallons of free product recovered	
Fort Drum, Watertown, NY Remedial Project Manager Fort Drum Environmental Division	Air Sparging, Free product recovery and GAC	Ground water		Full-scale remediation to recover free-phase petroleum product using ground water extraction and air stripping and GAC	2 recovery wells were installed and 2 GAC drums were used in series.	
Amcor Precast, Ogden, UT Shelly Quick Utah DERR	Density driven ground water air sparging and SVE	Soil and Ground water	Diesel and gasoline fuels TPH (51/190), benzene (1.3/4.7), toluene (2.4/9.4), ethylbenzene (0.78/2.7), total xylene (2.5/8.0), naphthalene (0.18/0.63).	In situ	12 ground water sparging wells, 3 downgradient extraction wells, and 3 vertical extraction wells were installed.	
DOE Integrated Demo, DOE Savannah River Site, Aiken, GA Terry Walton (803) 725-5218	Air Sparging, Organics in soil and ground water at nonarid sites	Soils, ground water 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	C tr b d
Denison Avenue Site, Cleveland, OH 1991 U.S. EPA Region 5 (312) 886-6143	Air Sparging	Ground water	BTEX			
Wayne Reclamation and Recycling, IN Duane Heaton (312) 886-6399	Air Sparging	Ground water	TCE, DCE, Vinyl Chloride, BTEX	Injection and extraction - In situ	Installation of injection wells.	V a e
Rochester Property, SC Sherri Panabaker (404) 347-7791	Air Sparging	Ground water	TCE, Bis-2-ethylhexyl- phthalate			
Fairchild AFB, Priority 1 Ous (OU 2) FT-, WA Cami Grandinetti (206) 553-8696	Air Sparging	Ground water	BTEX		Vapor extraction system installed in conjunction with an air injection well.	V a e
South Municipal Water Supply Well, NH Roger Duwart (617) 573-9628	Air Sparging	Ground water	PCE, TCA, TCE			
Applied Environmental Services, OU 1, NY Gerald Ridder (518) 457-0927 Jon Maria (212) 637-3967	Air Sparging	Ground water	Non-halogenated VOCs, Halogenated VOCs, Non-halogenated SVOCs, PAHs, BTEX		In situ	
Mystery Bridge Road/Highway 20, OU 2, WY	Air Sparging	Ground water	Benzene, Ethyl benzene, Xylenes	54 wells operated 8 to 15 at a time, 120 cfm, 0.7 - 1.0 inches of water.		C tc u d

Dan Thorton (303) 312-6215						p
Installation Restoration (IR) Site 11, NAS Northern Island, San Diego, CA	Terra Vac pilot SVE/ Air Sparging/ Catalytic Oxidation Systemging	Soil	Up to 250 pounds (33 gallons) per day of VOCs was effectively removed from the vadose zone and subsequently destroyed.			
NAS Fallon, NV 1994 U.S. Navy, Public Works Department (702) 426-2772	Bioslurping	Ground water	TPH			
Island of San Diego Garcia AFCEE/PA 3207 North Road Brooks AFB, TX 78235-5363 Tel: (210) 536-4228	Bioslurping	Ground water	Fuel (JP-5)	It has pulled out over 2,000 gallons of fuel during the first month of operation and about 1,000 gallons every month	In situ	
Naval Air Station, Fallon, Nevada NFESC, 560 Center Drive., Port Hueneme, CA 93043-4301	Bioslurping	Ground water	Fuel (JP-5)	An average of 24 gallons of fuel per day during operation, with a maximum removal rate of 60 gallons per day. Ground water removal has averaged 0.46 gallons per minute	In situ	
Dry Cleaning Facilities, Hutchinson, KS 1997 Douglas Dreiling 316-941-3921 Leo G. Henning 785-296-191	Chemical Oxidation Burns & McDonnell Wichita, KS Kansas Kansas Dept. of Health & Env.	Ground water	PCE		In situ	
Keesler AFB, MS 1997 James R. Gonzales 210-536-4324 james.gonzales@hqafcee.brooks.af.mil	In situ air stripping with horizontal wells AFCEE/ERT Technology Transfer Div. 3207 North Rd.—Bldg. 532 Brooks AFB, TX 78235	Ground water	Ground water	In situ		
Dry Cleaning Facilities, Hutchinson, KS 1997 Douglas Dreiling 316-941-3921	In situ air stripping with horizontal wells Burns & McDonnell 3839 Dora Wichita, KS 67213	Ground water	PCE	In situ		
DOE Demo Savannah River Site, SC 7/90-12/90 Mike O'Rear (803) 725-5541	In situ air stripping with horizontal wells	Soil & ground water	TCE & PCE Initial concen- trations: 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.	C
DOE Demo, Seattle, WA	Directional Wells	Ground water	Chlorinated solvents: Tetrachloro- ethylene	Two 100 mm diameter stainless-steel, pre-packed ground water	In situ	S tr fi

DOE; Michael Lubrecht, Marketing Manager, FlowMole Environmental Services Corp., Kent, WA; Hart Crowser, Seattle, WA (Consulting firm)				extraction wells.		
Buchanan, MI 1994 Billings & Associates (505) 345-1116 National Risk Management Research Laboratory (513) 569-7797	Subsurface Volitization & Ventilation System	Ground water	BTEX, PCE, TCE			
March Air Force Base, CA 1995 Michelle Simon (513) 569-7676 Jeff Bannon (818) 596-6900	UVB - Vacuum Vaporizing Well	Ground water	TCE - >94% removal, DCE	The UVB system consists of a ground water well, a negative pressure stripping reactor, an aboveground mounted blower, and a waste air decontami- nation system.		
Lockheed Aeronautical Systems Co. Burbank, CA David Bluestein (415) 227-0822	Dual Phase Extraction AWD AquaDetox/ SVE System	Soil & Ground water	2.2 ppm TCE; 11 ppm PCE; 6,000 ppm total VOC soil gas. Attained 98-99.99 % removal	In situ		
Major Car Rental Agency, Los Angeles, CA Terra Vac Corporation, James Keegan (714) 252-8900	Dual Vacuum Extraction (Dual Phase Extraction)	Ground water, Soil	Hydrocarbons, TPH	Vadose zone soil permeability range of 0.001 to >100 millidarcies	Vacuum extraction well includes a screened section in the vadose zone of contaminated soils and ground water.	I p d u p tl
Navy Fuel Farm Mike Radecki SOUTH WEST DIV	Free product recovery	Ground water	0.5-2.5 ft free product.		Captured in pit and pumped out with skimmers and french drains	
Privately Owned Gasoline Station Near Urban Drinking Water Source Connecticut DEP (203) 566-4630	Free product recovery	Ground water	Gasoline, BTEX	Immediate response from recovery wells and air stripping		
Navy Demo Seal Beach Navy Weapons Station, CA 1991 Vern Novstrup (805) 982-2636 Rebecca Coleman-Roush (805) 644-5892	Ground water vapor recovery system	Ground water	VOCs	In situ - air permitting	Injection & extraction wells are placed inside and outside of contami- nation area	V h t c e
McClellan AFB	Pilot-scale fluid/vapor extraction demonstration.	Soil & Ground water	VOCs. 1,200 lbs/year for contaminants removal.	In situ	95% of the ground water VOCs were transferred to vapor phase.	
EPA Demo San Fernando Valley Ground water Basin Superfund Site, CA 1990 Norma Lewis (513) 569-7665	Integrated vapor extraction & steam vacuum stripping	Soil & ground water	Initial concentration: up to 2.2 ppm TCE up to 11 ppm PCE Removal: up to 99.9% VOCs	Ground water: 1,200 gpm Soil gas: 300 ft/min	Ground water: Steam stripping in tower Soil: SVE	C b e
Airfield, Lemoore, CA 1994 (805) 982-4191	Steam Injection and Vacuum Extraction	Ground water	JP-5 (Jet Fuel)			
EPA Demo Huntington Beach, CA	Hot Water or Steam Flushing/	45,000 yd^3 of soil & goundwater	Diesel fuel, TPH, and	In situ	results not good, probably	

Paul dePercin EPA RREL	Stripping		TRPH 20-40% removal attained		because of poor application rather than technology delivery ineffective-ness
EPA SITE demo Pennsylvania Power & Light Stroudsburg, PA Eugene Harris EPA (513) 569-7862	Hot Water or Steam Flushing/ Stripping with CROW				
Lawrence Livermore National Laboratory Gasoline Spill Site Livermore, CA Kathy Kaufman University of California (510)422-2646	Hot Water or Steam Flushing/ Stripping	Ground water	Benzene level in soil greater than 50 ppm. Over 7,600 gallons of gasoline removed during demonstration.	In situ	6 steam injection/ electrical heating wells, 3 electrical heating wells, 3 ground water and vapor extraction wells were installed.
Xerox Facility Oak Brook, IL	Hydro- fracturing	Soil & Ground water	VOCs	In Situ	SVE of organic solvents. 10 times increase in vapor extraction; 30 times increase in area covered; pore water infiltration decreased
UST site, Dayton, OH	Hydro- fracturing	Soil & Ground water	BTEX	In Situ	In situ bio-remediation of BTEX/UST site. 100 times increase in water flow; 75% increase in bio-remediation rate
Fuel Dispensing Area 1595, Watertwon, NY 1994 Fort Drum Environmental Division, Watertown, NY	Ground water Extraction & Air Stripping	Ground water	BTEX		
Lawrence Livermore National Laboratory 1993 (510)422-2646 UCA, Office of Tech Transfer (510) 748-6595	Dynamic Underground Stripping	Groundwater	BTEX, FHC, Benzene		
Site Demo March AFB, CA Michelle Simon EPA RREL (513) 569-7469 Jeff Bannon WESTON (818) 556-5226	In-Well Air Strippings: air lift pumping, in situ vapor stripping, and air sparging	Soil & Ground water	30 ppb TCE at well inlet Attained < 1 ppb of TCE	In Situ	
Installation Restoration (IR) Site 9, NAS Northern Island, San Diego, CA	EG&G NoVOCs™ in-well stripping technology	Ground water			
Savannah River Site, GA 1994 National Risk Management Research Laboratory (513) 569-7631	High-Energy Electron Irradiation	Ground water	Chlorinated Solvents and Fuels		

Westinghouse Savannah River Site, Aiken, SC 1997 Mark Phifer 803-725-5222 mark.phifer@srs.gov	Passive Treatment Wall Westinghouse Savannah River Co. Aiken, SC	Ground water	TCE, cDCE, CT, NO (III)	In Situ		
Former Plating Facility, NY 1997 Diane Clark 315-655-8161 diane.clark@stearnswheler.coom	Passive Treatment Wall Stearns & Wheler One Remington Park Dr. Cazenovia, NY 13035	Ground water	TCE, cDCE, VC	In Situ		
Lowry AFB, CO 1997 William A. Gallant 303-452-5700 gallabil@versar.com	Passive Treatment Wall Versar, Inc. 11990 Grant St., Ste. 500 Northglenn, CO 80233	Ground water	TCE	In Situ		
NAS Moffett Field, CA 1997 Charles Reeter 805-982-4991 reetercv@nfesc.navy.mil	Passive Treatment Wall U.S. Navy - NFESC 1100 23rd. Ave., Code 411 Port Hueneme, CA 93043-4370	Ground water	TCE, PCE, DCE	In Situ		
Tonolli Corporation, PA (Battery Recycling/ Disposal) Linda Dietz, USEPA, 215-597-6986	Passive Treatment Wall	Ground water	Heavy Metals: Lead			
Lowry Air Force Base, CO Richard Muza (EPA Region 8) (303) 312-6595	Iron Reactive Walls	Ground water	Trichloro- ethylene (1,260 ppb	A subsurface wall of iron filings through which the contaminant plume migrates under natural ground-water flow		D p e a
Somersworth Sanitary Landfill Site, NH (Industrial Landfill/ Municipal Landfill) Roger Duwart, USEPA, 617-573-9628	Passive Treatment Wall	Ground water	Non- halogenated volatiles			
Brown's Battery Breaking Site, OU 2, PA (Battery Recycling/ Disposal) Richard Watman, USEPA, 215-597-8996	Passive Treatment Wall (limestone barrier)	Ground water	Heavy metals: Lead			
Tonolli Corporation	Permeable Reaction Wall	Ground water	Lead Cadmium Arsenic Zinc Copper	Trench Limestone	Operational	
Somersworth Sanitary Landfill	Permeable Reaction Wall	Ground water	Trichlorethene (0.005 mg/L) Vinyl Chloride (0.005 mg/L)	Funnel and Gate Zero-Valent Iron	Operational	
Rocky Flats Plant (USDOE) - Buffer Zone	Permeable Reaction Wall	Ground water	Carbon Tetrachloride Tetrachloroethene Trichloroethene	Funnel and Gate Zero-Valent Iron	Operational	
Monticello Mill Tailings (USDOE) - Operable Unit 3	Permeable Reaction Wall	Ground water	Arsenic (0.05 mg/L) Molybdenum (0.183 mg/L) Radium 226 (5 pCi/L)	Funnel and Gate Zero-Valent Iron	Operational	

			Selenium (0.05 mg/L) Uranium (1.1 mg/L)		
Lake City Army Ammunition Plant (NW Lagoon) - Operable Unit 3	Permeable Reaction Wall	Ground water	1,1-Dichloroethene (0.007 mg/L) Trichloroethene (0.005 mg/L) Vinyl Chloride (0.002 mg/L)	Funnel and Gate Zero-Valent Iron	Operational
F.E. Wareen Air Force Base - Operable Unit 2	Permeable Reaction Wall	Ground water	Trichloroethene		Operational
Brown's Battery Breaking Site	Permeable Reaction Wall	Ground water	Beryllium (1.9x10-4 mg/L) Cadmium (8.8x10-4 mg/L) Lead (<0.003 mg/L) Manganese (0.05 mg/L) Nickle (0.0029 mg/L) Sulfate (0.027 mg/L)	Calcium Hydroxide Magnesium Hydroxide	Design
Arrowhead Associates/Scovill Corporation	Permeable Reaction Wall French	Ground water	Chromium Cyanide	Zero-Valent Iron Design	Design
Uranium Mine Tailings Site, Fry Canyon, UT 1999 David L. Naftz 801-975-3389 dlnaftz@usgs.gov	Permeable Reaction Wall USGS District Office - Salt Lake City, UT	Ground water	U	In Situ	
Bodo Canyon Disposal Cell Mill Tailings Site, Durango, CO 1999 Brian Dwyer 505-845-9894 BPDwyer@sandia.gov	Permeable Reaction Wall Sandia National Laboratory Albuquerque, NM	Ground water	U, As, Se, Zn, Ra-226, Mo, Mn	In Situ	
Launch Complex B, Cape Canaveral Air Center, FL 1999 Major Edward Marchand 210-536-4364	Permeable Reaction Wall U.S. Air Force Center for Environmental Excellence Brooks AFB, TX	Ground water	TCE, DCE, VC	In Situ	
Westing- house Savannah River Site, Aiken, SC 1998 Mark Phifer 803-725-5222 mark.phifer@srs.gov	Permeable Reaction Wall Westinghouse Savannah River Co. Aiken, SC	Ground water	TCE, cDCE, CT, NO (III)	In Situ	
X-231A Site, Portsmouth Gaseous Diffusion Plant, OH 1998 R.L. Siegrist rsiegris@mines.edu	Permeable Reaction Wall ORNL/Colorado School of Mines	Ground water	NAPLs, DNAPLs	In Situ	
LEAP Permeable Barrier Demonstration Facility, Portland, OR 1998 Robert Bowman 505-835-5992 bowman@nmt.edu	Permeable Reaction Wall New Mexico Tech Socorro, NM	Ground water	PCE, Cr(VI)	In Situ	

100 HR-3 Operable Unit, Hanford Reservation, WA 1998 John Fruchter, PI 509-376-3937 js_fruchter@pnl.gov	Permeable Reaction Wall PNNL	Ground water	Cr(VI)	In Situ	
Canadian Forces Base, Canada 1993 Waterloo Centre for Ground Water Research (519) 885-1211 Centre for Excellence (416) 323-4476	Permeable Reaction Wall	Ground water	TCE, PCE, DCE		
Borden Aquifer, Canada 1994 Waterloo Centre for Ground Water Research (519) 885-1211 Centre for Excellence (416) 323-4476	Permeable Reaction Wall	Ground water	BTEX, Benzene and Toluene		
Air Force Demo Hill AFB, UT Maj. Mark Smith USAF Tyndall AFB, FL (904) 283-6126	"Funnel and Gate" Passive Treatment Wall	Ground water			
Los Alamos National Laboratory Ken Bostick Mail Stop J495 Organization EES-15 Los Alamos National Laboratory	Passive Treatment Wall Barriers and post-closure monitoring completion	Ground water			

Sources: *Innovative Treatment Technologies: Annual Status Report (Eighth and Tenth Editions, Nov. 1996 and Feb. 2001). Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America (1st and 2nd Editions, Aug 1996 and Jun 2000).*

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 metals removed using dilute mineral acids	Able to achieve drinking water standards.
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	Ground water	PCP reduced to <1 ppm. lowest flow removed 99% of contaminants	In mix tank, pH is adjusted & inorganic nutrients added	Mixing	Discharged to POTW or reused on-site	Runs as anaerobic or aerobic. Does not treat metals.
DOI Demo Late Summer 1993 Paulette Altringer Darren Belin (801) 584-4152 or 4155	Biological arsenic remediation	Wastewater	Arsenic reduced from 13 to <0.5 mg/l	Addition of anaerobic sulfate-reducing bacteria	Two stage reactor, arsenic precipitation and column system	Minimum volume arsenic precipitate sludge	Advantage: reduction in generation of sludge volumes compared to typical ferris arsenic precipitation circuits.
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 treatment as a polishing step	Alternative rinsing technology oxidized cyanide by activating natural or introduced populations of cyanide-oxidizing bacteria.
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 supplements.	Selenium is precipitated and removed by flushing or cross-flow filtration	Uranium wastewaters may be treatable. Technology involves biostimulation of indigenous or introduced selenium-reducing bacteria.
Navy Demo, Naval Weapons Station Seal Beach, CA Steve MacDonald (310) 594-7273 Carmen Lebron (805)982-1615	Bioremediation of aromatic hydrocarbons	Soil & Ground water	1 ppb to 4 ppm of BTEX	Three 80-liter bioreactors at combined capacity of 72 liters/day	Native micro-organisms. Site soil is placed in bioreactors and contaminated ground water is pumped through bioreactors	Effluent cleaned to drinking water standards for BTEX	
EPA Demo St. Joseph, MI Ronald Lewis (513) 569-7856 Steve Lupton (708) 391-3224	Immobilized cell bioreactor (ICB) biotreatment system	Ground water 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	Contaminants to CO_2, water, and biomass. The effluent produced is reinjected	Advantages: high treatment capacity, compact system design, reduced operations costs.
Air Force & DOE Demo Tinker AFB, OK	In situ & aboveground biological	Ground water	80% destruction of TCE	In situ or in a bioreactor	Uses methane degrading bacteria to co-	TCE degraded	System using altered micro- organisms is being tested at Hauscomb AFB, MA.

1989 Alison Thomas (904) 283-6028	treatment of trichloro-ethylene				metabolize TCE		
Atlanta Gas Light Company Augusta, GA 1997 Jim Ullery 706-722-3490 JUllery@setechctr.org	Bioreactor Southeastern Technology Center (STC)	Ground water	PAHs, BTEX, Metals				Mobile Bioreactor Demonstration setechctr.org/Environmental/mobile.htm
Hanscomb AFB, MA Alison Thomas USAF (904) 283-6303	Bioreactor. Testing of constitutive TCE degrading microbe	Ground water	550 ppb TCE. Attained about 85 ppb.				
Dow Chemical Site, TX Alison Thomas USAF Tyndall AFB	Bioreactor: fluid bed reactor	Ground water	Chlorobenzene degradation. 140 ppm chlorobenzene. Attained <5 ppb chlorobenzene				
Burleigh Tunnel Silver Plume, CO Rick Brown Colorado Dept. of Health (303) 692-3383 James Lewis (303) 692-3383	Manmade wetland ecosystem based treatment	Ground water	50-60 ppm of zinc. Attained 99% reduction in 3 months 99% removal of iron, 94% removal of lead, 84% reduction in nickel.				
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		Manual developed - Wetland Designs for Mining Operations - available from NTIS.
Big Five Tunnel, CO (near Idaho Springs) Edward Bates (513) 569-7774, Thomas Wildeman (303) 273-3642	Constructed Wetlands	Wastewater	Metals, acid mine drainage	Principal components - organic soils, microbial fauna, algae, and vascular plants		Precipitated and adsorbed metals as hydroxides and sulfides settle in quiescent ponds or are filtered out as water percolates through the soil or the plant substrate.	The process can be adapted to treat neutral and basic tailings solutions.
Bear Creek, Oak Ridge, TN Technical: A. J. Stewart; Oak Ridge, Tennessee (800)356-4USA 4USA@ornl.gov	Constructed Wetlands	Ground water	Nitrate and Uranium	Principal components - pea gravel and various species of emergent aquatic plants. Cell pump powered by solar panels. Other measured parameters			Removal efficiencies greater than 90% for nitrate are expected.

				are pH, dissolved oxygen concen-tration, and water temperature.			
Naval Amphibious Base in Little Creek, Virginia J.P. Lefave NFESC Code 411 Port Hueneme, CA 93043 (805) 982-1973 DSN: 551-1973	Constructed Wetlands	Surface water, stormwater runoff	Non-point source pollution	The cells each measure 60 X 650 ft. Water flows from the channel to the cells via 24-inch diameter pipes with equipped with one-way check valves.	The site was formerly covered with a near monoculture of Phragmites which were sprayed with the herbicide Finale after they sprouted on the sideslopes after construction of the cells.		Plants used: Spartina alterniflora, Spartina patens, Panicum amarum, Iva

Sources: *Innovative Treatment Technologies: Annual Status Report (Eighth and Tenth Editions, Nov. 1996 and Feb. 2001). Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America (1st and 2nd Editions, Aug 1996 and Jun 2000).*

EPA Demo National Lead Industry, NJ 10/93 Carolyn Esposito (908) 906-6895 Gary Vaccaro, SAIC (201) 489-5200	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	Regeneration or incineration of the metals- saturated sponge	In situ directly inserted into well or ex situ. Sponge can scavenge metals in concentrated levels of ppm and ppb from industrial discharges. $340 per 1000 gallons
Pease Air Force Base, Newington, NH Ronald Turner (513) 569-7775	Adsorption (Ambersorb® 563 adsorbent)	Ground water	Vinyl Chloride, 1,1-Dichloro- ethene, Trichloroethene			Condensed contaminants are recovered through phase separation	Ambersorb 563 adsorbent has 5 to 10 times the capa city of granular activated carbon (GAC) for low concentrations of volatile organic com-pounds (VOC).
Superfund Site: Western Processing, WA (near Seattle) Mark Benjamin, University of Washington, Seattle, WA 98195, (206) 543-7645	Adsorption (Adsorptive Filtration)	Ground water	Soluble and particulate Zinc				Adsorptive filtration removes inorganic contaminants (metals) from aqueous waste streams.
Superfund Site: The Rocky Mountain Arsenal, Operable Unit 17, Comerse City, CO	Sequence of unit processes including precipitation, filtration, UV/chemical oxidation, GAC, air stripping and Adsorption (Activated Alumina)	Wastewater	VOCs: benzene, toluene, TCE, PCE; Metals: arsenic, chromium, lead.			Discharge of treated effluent to the sanitary sewer and offsite disposal of sludge and residuals.	Treatment goals meet Colorado Basic Standards for Ground Water (CBSG) and the state MCLS.
Superfund Site: Valley Wood Preserving, Inc., Turlock, CA	Excavation and cement-based fixation for contaminated soil. Chemical treatment followed by Adsorption (Activated Alumina)	Soil and ground water	Chromium and arsenic.			Backfilling excavated area with treated soil. Treated water is reinjected to ground water and/or discharged to percolation ponds.	Total estimated cost for this remedial action is $3,850,000 with annual O&M cost of $224,000.
Superfund Site: Motor Wheel, Lansing TWP, MI	Backfilling, capping, and slurry wall containment for contaminated soil. Aeration, separation, air stripping, and Adsorption (Activated Alumina) for ground water.	Soil and groundwater	VOCs: benzene, PCE, TCE, toluene, and xylenes; Organics: PAHs, PCBs, and pesticides; Metals: arsenic, chromium, and lead				Activated alumina adsorption process removes fluoride from ground water.
Superfund Site: Perham Arsenic, Perham, MN	Filtration and Adsorption (Activated Alumina) for ground water on site	Ground water	Arsenic cleanup goal of 50 ppb from up to 1260 ppb in plume.			Discharge of treated effluent to the aquifer; Disposal of alumina filter media and filtered solids	The overall Present Worth costs are $2,548,776, with the annual O&M costs of $217,806 (year 1 to 6)
Englin AFB Edward G. Marchand HQ AFCESA/ RAVW Tyndall AFB,FL (904) 283-6023	Rotary air Stripper-high iron content	Soil & Ground water	>99% removal				

DOE Demo- Savannah River Site, SC G.E. Turner, DOE Savannah R. Oper. Office Env. Rest, Aiken, SC	Full-scale pump and treat using aboveground air stripping.	Ground water	Influent concentrations: up to 48 ppm for TCE, up to 12 ppm for PCE. Average VOC removal efficiencies in air stripper: >99.9%	In Situ	7 horizontal wells installed; only 2 wells used in field demonstration		Total Capital Cost: $4,103,000; Total Annual Operating Cost: $149,200. $0.20/1,000 L ($0.75/1,000 gallons)
Langley AFB, VA Vern Bartels Remedial Project Manager	Vacuum assisted well point extraction system and aboveground air stripping.	Goundwater	Total Recoverable Petroleum Hydrocarbons: 25 to 4,100 ppb on ground water, >100 ppm in soil.				Total Capital Cost: $569,739; Annual Operating Cost: $216,561
McClellan AFB, CA Remedial Project Manager McClellan AFB	Aboveground air stripping.	660 million gallons of ground water	Estimated 33,000 kg of VOCs released. Influent VOC concentration at 60 ppm		7 extraction wells were installed. 2 GAC units in series were used to polish liquid phase after stripping.	Effluent below permitted discharge levels.	Total Capital Cost; $4,000,000; Total Annual Operating Cost: $1,240,000.
Army Demo Fort Dix, NJ Steve Maloney (217) 373-6740	Catalytic Decontami- nation and Air stripping	Ground water	Reduction: 0% TOC up to 90% VOC	Ex situ	Ozone injection and stripping	Air stream - treated in catalytic unit and recycled	Metal precipitate clogging and biofouling can occur.
Verona Wellfield Battle Creek, MI	GAC as pretreatment for air stripper.	Ground water	12,850 ppb TVOC Attained: 11 ppb				
U.S. Coast Guard Traverse City, MI	GAC used with Pump/treat	Ground water	10,329 ppb of Toluene. Attained: < 10 ppb		Discharge to municipal sewer.		
Love Canal Niagara Falls, NY	GAC system for leachate treatment.	Ground water	28,000 ppb Benzene. Attained: < 10 ppb				
Fort Drum, Watertown, NY Remedial Project Manager Fort Drum Environmental Division	Air Sparging, Dual Phase Extraction and GAC	Ground water		Full-scale remediation to recover free-phase petroleum product using ground water extraction and air stripping and GAC	2 recovery wells were installed and 2 GAC drums were used in series.		Total Capital Cost: $958,780; Total annual Operating Cost: $129,440.
Milan AAP Milan, TN USAEC ETD (410) 671-2054	GAC for explosives contaminated ground water.	Ground water	1.0 - 2.0 mg/L total explosive. Attained: ND (< 10 ppb) for all explosives				
Amoco Petroleum Pipeline Constantine, MI	Air Sparging, Dual Phase Extraction and GAC to recover free product and treat ground water.	775 million gallons of ground water	300,000 to 2 million gallons of gasoline, fuel oil, and kerosene	In situ air sparging was subsequently added to treat the saturated zone. 4 extraction wells and 30 air sparging wells were installed. 2 GAC vessels in series	118,000 gallons of free product recovered		Capital Cost: $297,000 for ground water recovery and treatment, $375,000 for air sparging. Annual Operating Cost: $475,000 $3 per 1,000 gallons of ground water treated.
Commen- cement Bay South Tacoma Channel, Tacoma, WA Kevin Rochlin Remedial Project Manager U.S. EPA	2 liquid-phase GAC	281.7 million gallons of ground water	Specific VOCs at influent: 13 to 2,000 µg/L. DCE up to 100 ppb, PCA up to 300 ppb, PCE up to 5.4 ppb, TCE up to 130 ppb. Attained: Specific VOCs at effluent: 1 to 13 µg/L.	Full-scale application of ground water extraction followed by GAC treatment in conjunction with an SVE system. 7 ground water extraction wells were installed and 2 liquid-phase GAC containers were operated in			Total cost: $1,343,701

				parallel.			
EPA Demo Kerr-McGee Chemical Corp., WI 1993 Douglas Grosse (513) 569-7844	Ion Exchange: Electro- chemical reduction & immobilization	Ground water	Hexavalent chromium and other heavy metals	In situ requires excess ferrous ions - maintain pH	Electro- chemical reactions generate ions for removal of hexavalent chromium	Clean water is reinjected into ground	Ex situ can be used to maximize rate and removal.
Army Demo USACE-WES, MS Mark Bricka (601) 634-3700	Ion exchange: Xanthate treatment	Ground water & wastewater	Heavy metals	Ion exchange with xanthated material	Precipitation, sedimen- tation, and filtration	Concentrated metal sludge	Offers many advantages over hydroxide precipitation.
EPA Demo Palangana Uranium Mine Site, TX 7/93 Annette Gatchett (513) 569-7697	Precipitation/ Filtration	Ground water	Low-moderate levels of NORM (uranium, radium-226, thorium-230)	Complexing, adsorption, and absorption	URAL complexing agent	Treated water to holding pond	
Coakley Landfill New Hampshire	Precipitation: Pretreatment of ground water by hydroxide precipitation with lime,	Ground water	Cr - 330 ppb Ni - 122-200 ppb As - 10-90 ppb Attained: Cr - 50 ppb Ni - 100 ppb As - 50 ppb		Used air stripping for removal of VOCs		
Stringfellow Acid Pit Site California	Precipitation.	Water	Cr - 1.5-270 ppm Cd - 0.32-9.3 ppm Zn - 2.2-300 ppm Cu - 1.7-20 ppm Attained: Cr - 0.5 ppm Cd - 0.11 ppm Zn - 2.61 ppm Cu - 2 ppm	Pretreatment for the removal of metals and organics, then POTW			
Winthrop Landfill Winthrop, ME	Precipitation	Ground water	As - 0.1-0.8 ppm Ni - 0.04 ppm Zn - 0.2-0.6 ppm Attained: As - 0.05 ppm Ni - 0.04 ppm Zn - 0.18 ppm	Pilot test of metals from the ground water by precipitation			
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%	Ground water extraction	Built an on-site vacuum for emissions control Contaminated residual oil incinerated off-site	Three mobile units currently available. Electroplating site.
Wastewater Technology Center John Martin U.S. EPA NRMRL (513) 569-7676	Separation	Ground water	VOCs. 99% Removal efficiency				
EPA & DOE Demo	Separation: Filtration	Ground water 58-95%	"Polishing" filtration process for heavy	Specific control - water chemistry,	Sorption, chemical	Concentrated waste sludge	Capital - $150K

Rocky Flats Facility, CO 7/90 Annette Gatchett (513) 569-7697		removal of uranium	metals and non-tritium radio-nuclides (NORM, LLRW, TRU). Uranium in ground water influent at filtration system concentration 40-100 mg/L	water flux, and bed volume	complexing, and hydroxide precipitation		Operation - $0.40 to $0.53/1,000 L $1.50 -$2.00/1,000 gallons treated. Colloid sorption filter for metals and nontritium radionuclides commercial scale SITE demo.
EPA Demo American Creosote Works, FL 1991 Kim Lisa Kreiton (513) 569-7328 EPA RREL John Martin (513) 569-7758	Membrane Separation	Ground water	PAHs, smaller phenolics Removal: 90% PAH 80% creosote 25-30% smaller phenolics		Positive pressure membrane hyper-filtration unit	Clean H_2O to POTW, concentrated contami- nants to holding tanks	$228- $1,739/1,000 gallons treated. $500K - $1.2M annual
DOI Demo Birmingham, AL Manassas, VA 1992 Ronald H. Church (205) 759-9446	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 poly-acrylamide	Pipe delivery system used as mixing system to minimize quantity of feed used. Waste should be in slurry form	The "clean" water can be discharged. Flocculated material becomes solid waste for a landfill	Polymer costs are $0.50-0.60 per ton of dry solids produced when polymer is bought in bulk.
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 of the discharge water ranged from 12 to 17, with the underflow discharge containing about 31% solids	Polymer costs: $0.50/lb when bought in bulk. Focus of DOI/USACE test is removal of suspended particulates from dredging of sediments.
EPA SITE Demo Selma Pressure Treating Selma, CA 11/90 Edward Bates (513) 569-7774	Pretreatment separation/ Solidification/ Stabilization with silicate compounds	Ground water, soil, sludge	Organics and inorganics	Silicate compounds	Pretreatment separation of coarse and fine materials	PCP leachate concen- trations reduced up to 97%. As, Cr, Cu immobilized	Applied to a wide variety of hazardous soils, sludges, and wastewaters.
DOE Integrated Demo, 4 DOE sites: (1) Hanford (2) Fernald, ID (3) Oak Ridge (4) Savannah River 2/91 Roger Gilchrist (509) 376-5310	Separation: USTs, emphasizing the single-shell storage tanks located at the Hanford site	Ground water, 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: characteri-zation /retrieval and separations of low-level waste	Parameters vary among technologies	Parameters vary among technologies	The UST-ID program will be used at Hanford, Fernald, Idaho, Oak Ridge, and Savannah River. Most UST waste was generated by processes used to separate nuclear fuels from other components.
DOI, Army, EPA Demo Saginaw Bay Confined Disposal Facility, MI; Toronto, Canada 10/91 to 6/92 S. Jackson Hubbard	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, silts, clays, and waste-water	Demo was part of the Assessment and Remediation of Contaminated Sediments (ARCs) Program.

(513) 569-7507							
EPA Demo Palmerton Zinc Superfund Site, PA 1990 John Martin (513) 569-7758	Membrane microfiltration	Liquid wastes	Solid particles in liquid wastes-removal averaged 99.95% for Zn & TSS	Filter press 45 psi Shallow aquifer with dissolved heavy metals	Tyvek (T-980) spun-bound olefin filter	Filter cake 40-60% solids	Best for treating waste less than 5,000 ppm. $213K - $549K annual
Naval Air Station North Island, San Diego, CA Ronald Turner (513) 569-7775	Separation (Cross-Flow Pervaporation System)	Ground water	Organics, primarily TCE - 98% reduction	TCE influent concentrations - 250 ppm, flow rate - 10 gpm			The ZENON Environmental Inc. cross-flow pervaporation technology is a membrane- based process that removes VOC from aqueous matrices.
Harris County John Blount (713) 956-3000	Trickling Filter (Sprinkler Irrigation)	Wastewater	BOD, TSS	BOD load rate - 45 lbs./day/1000 sq. ft.. Hydraulic load rate - 235 gallons/day/sq. ft.		Effluents are chlorinated and stored in a pump tank. They are distributed to lawns through an automatic irrigation system.	
Tracey, CA 1992 National Risk Management Research Laboratory (513) 569-7697	Photochemical	Ground water	TCE, PCE, DCA				
Lawrence Livermore Site 300, CA 1992 Vulcan Peroxidation Systems, Inc. (602) 790-8383 National Risk Management Research Laboratory (513) 569-7697	Chemical Oxidation	Ground water	VOCs				
EPA Demo Coleman- Evans Site, FL Norma Lewis (513) 569-7665	Soil washing/ catalytic ozone oxidation	Soil, sludge, & ground water	Organics - 1-20,000 ppm	Soil washing enhanced by ultrasound followed by oxidation	Soil particles larger than 1 inch are crushed	Carbon filter for off-gas	Excalibur technology.
Navy Demo Bangor SUBASE, WA Spring 1993 Carmen LeBron (805) 982-1616	Advanced Oxidation Process. Bench-scale TNT and RDX treatability test. Recirculating UV/ozone reactor. 30-minute retention.	Ground water	Beginning levels: 7 ppm TNT; 600 ppb RDX Ordnance - treated to 2.9 ppb TNT and 0.8 ppb RDX	Maintain pH.	UV oxidation, H_2O_2 to generate hydroxyl radicals	Possible toxic byproducts	Full scale system being designed.
Navy Demo U.S. Navy Site, NJ 1991 Andy Law (805) 982-1650	Advanced Oxidation Process	Ground water	Organics - TOC 50-100 ppm	Maintain pH	UV oxidation, H_2O_2 to generate hydroxyl radicals	Contaminant destruction	
Winthrop Superfund Site, ME	UV/oxidation	Ground water	Pretreat for iron, then UV/oxidation solvents. 5 ppm DMF. Attained:				

Dr. Raymond Machacek Arthur D. Little, Inc. (617) 498-5580			< 5 ppb				
Milan AAP Milan, TN USAEC ETD (410) 671-2054	UV/oxidation	Ground water	Explosives: 20.0 ppm total explosives Attained: ND (10 ppb) for all explosives				
Air Force & EPA Demo Edwards AFB, CA 3/93 Richard Eilers (513) 569-7809	UV/oxidation: CAV-OX® Process	Ground water & wastewater	Organics - 96-100% reduction	H_2O_2 and metal catalysts added if needed	Hydro- dynamic cavitation and UV oxidation	Contaminant destruction	Cannot handle free product or highly turbid streams.
EPA Demo Lake Charles Treatment Center, LA Randy Parker (513) 569-7271	PO*WW*ER ™ evaporation & catalytic oxidation	Ground water & wastewaters	Volatile & non-volatile organic compounds, salts, metals, volatile inorganics	0.25 gpm pilot-plant	Evaporation & oxidation	Concentrated contaminant solution disposed of or treated further	$110/1,000 gallons treated.
EPA Demo San Jose, CA 3/89 Norma Lewis (513) 569-7665	Ultraviolet radiation & oxidation	Ground water	Halogenated hydrocarbons, VOCs, pesticides, PCBs - 99% TCE, 58% 1,1-DCA, 85% 1,1,1-TCA removal	UV,H_2O_2 destruction	Tank with air compressor, O_3 generator, and H_2O_2 feed	Offgas to ozone destruction	20 commercial systems installed.
DOE Demo Kansas City Plant, MO Sidney B. Garland II (615) 579-8581	Ultraviolet radiation, hydrogen peroxide, and ozone	Ground water	TCE concentration above 10,000 µg/L in ground water. >99.5% VOCs were destroyed.	30% downtime for maintenance and repair	Flow rate has averaged 15% of design rate		Total Capital Cost: $1,383,400; Annual Operating Cost: $355,200.

Sources: *Innovative Treatment Technologies: Annual Status Report (Eighth and Tenth Editions, Nov. 1996 and Feb. 2001). Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America (1st and 2nd Editions, Aug 1996 and Jun 2000).*

DOI Demo Bureau of Mines Tuscaloosa Research Center, AL C.W. Smith (205) 759-9460	Well Point Containment	Ground water	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 of ground water required after well point pumping begins	Well points are used to alter water tables, remove leachate for treatment, or control ground-water movement
Commencement Bay, South Tacoma Channel, Tacoma, WA Kevin Rochlin Remedial Project Manager U.S. EPA Region 10 Seattle, Washington	Ground Water Pumping (Pump and Treat)	Ground water	VOCs: DCE, PCA, PCE, and TCE 20% of contamination is in the top 32.5 ft. 80% is in the 32.5 to 40 ft. depth interval.	A pumping rate of 200 gpm is estimated to induce a 0.75 foot drawdown at a radius of influence of 200 ft. A pumping rate of 500 gpm is estimated to induce a 1.9 foot drawdown at the same radius.			As of Feb.23, 1994, 281,700,000 gallons of groundwater have been pumped and an estimated 10,361 pounds of VOCs have been treated and removed by the GAC treatment system.
DOE's Lawerence Livermore Nat'l Lab (LLNL), Livermore, CA	Ground Water Pumping (Pump and Treat)	Ground water	VOCs, BTEX, Chromium, Lead, and Tritium. VOCs underlie approximately 85% of the LLNL site over an area of about 1.4 square miles. The VOC plume thickness varies between 30 and 100 ft and rarely exceeds 200 ft in depth. The total volume of undiluted VOCs has been estimated at less than 200 gallons.	Treatment Facility G scheduled for initial operation in 1996 will likely be installed as 2 separate facilities to treat VOC contaminated ground water at a rate of 30 GPM by air stripping followed by GAC treatment of offgases. The Trailer 5475 facility scheduled for detailed design in 1997 or 1999 will treat ground water to remove VOCs (primarily TCE) in a closed loop UV/H2O2 , air stripping and GAC facility			The LLNL ground water treatment program is in the early stages of implemen- tation. Treatment facilities A,B,C and F have operated with minimal extraction wells in a test mode since their startup. Treatment facility D (TFD) began operation in October 1994. Little detailed or meaningful performance information is available
Operable Unit (OU) D, McClellan Air Force Base, CA	Ground Water Pumping (Pump and Treat)	Ground water	TCE, PCE, DCE. Contaminants in ground water have been found to exist in 3 separate phases at McClellan: sorbed to the soil matrix, solublized in porewater, or as free product. Contamination is additionally present dissolved in soil gas in the vadose zone.	The GWTP operates 24 hours/day, 365 days/year. At least one operator is on duty at all times. The plant has full spare backup pumps and blowers and backup GAC and heat exchange capacity at low flow rates. Control loops are configured to provide automatic shutdown during process upsets.	During 1993 the GWTP: Treated over 73 million gallons of Ground water. Was online 98% of all available time. Consumed 2.2 million cubic ft of natural gas, 200,000 kwhrs of electricity, approximately 650 gallons of sodium hypochlorite, and over 50 gallons of sodium hydroxide		Over 44,000 lbs of VOCs have been removed since startup. Influent VOC concentrations were approximately 60 ppm in 1987 and have decreased to approximately 4 ppm.
OU B/C, McClellan Air Force Base, CA	Ground Water Pumping (Pump and Treat)	Ground water	TCE, PCE, DCE. Contaminants exist in 3 separate phases at McClellan: sorbed to the soil matrix, solublized in porewater, or as free product. Contamination is additionally present dissolved in soil gas in the vadose zone.	The plant has full spare backup pumps and blowers and backup GAC and heat exchange capacity at low flow rates. GWTP II, which operates within OU B, is a simple arrangement of			Landfill, Disposal Pit, UST's During 1993 the GWTP: Treated over 73 million gallons of ground water. Consumed 2.2 million ft3 of natural gas, 200,000 kwhrs of

				two ground water extraction wells pumping approxi-mately 2 GPM each through a double- contained pipeline equipped with a leak detection system to a holding tank. The ground water is then pumped through a bag filter and treated by two GAC adsorption units in series.			electricity, approximately 650 gallons of sodium hypochlorite, and over 50 gallons of sodium hydroxide. GWTP II had processed a total of 7.9 million gallons of ground water as of January 1994
Twin City Army Ammunition Plant, New Brighton, MN Remedial Project Manager	Full-scale of pump and treat	Ground water	TCE concentration greater than 10,000 ppb in ground water. 99.9% removal of VOCs in influence	In Situ			Total Capital Cost: $8,034,454; Total Annual Operating Cost: $588,599. $0.12 per 1,000 gallons treated.
Langley Air Force Base, VA Vern Bartels, Remedial Project Manager Langley AFB	Ground Water Pumping (Pump and Treat)	Ground water	Benzene, Toluene, Ethylbenzene, Xylenes (BTEX) and Total Petroleum Hydrocarbons (TPH) - Primary constituents of JP-4 fuel are alkanes, cycloalkanes, alkylbenzenes, indans/tetralins, naphthalenes - Total Recoverable Petroleum Hydrocarbons - 25 to 4,100 ppb in ground water; >100 ppm in soil	Groundwater Extraction using a Vacuum Assisted Well Point Extraction System and Aboveground Air Stripping - Extraction - 16 vacuum extraction wells connected by a header pipe to a central vacuum system; wells extend to approximately 14 ft. below ground surface - Extraction network has an average flow rate of 32 gpm (2 gpm per well); vacuum pump provides 24-25 in of Hg Separation - initial oil/water separation occurs in a vacuum decanter followed by a high efficiency oil/water separator; oil phase is sent to a storage tank			Total Capital Costs - $569,739 (1992) (including demolition and excavation, system installation, startup, mobilization and site preparation) - Annual Operating Costs - $216,561 (1993), $143,047 (1994) (including labor, materials, and equipment) - An estimated total cost for completing the cleanup is not available at this time
DOE Demo, Kansas City Plant, MO Environmental Restoration G.P. Keary, Environmental Restoration Program Manager	Ground Water Pumping (Pump and Treat)	Ground water	Chlorinated Aliphatics; includes Tetrachloroethene (PCE), Trichloroethene (TCE), 1,2-Dichloroethenes (1,2-DCEs), and Vinyl Chloride PCBs, Petroleum Hydrocarbons, and Metals - TCE concentrations of > 10,000 ~g/L in ground water	Groundwater Extraction with Advanced Oxidation Processes (AOPs) - 14 extraction wells and one trench; screened intervals of wells ranged from 27 feet to approximately 47 feet below ground surface; flow rates ranged from 0.9 to 5 gallons per minute (gpm) based on a design flow rate of 2 gpm - Interceptor			Industrial site. Total Capital Costs: $1,383,400 (including equipment, site preparation, construction/ engineering, startup) - Annual Operating Costs: $355,200 (including mainte-nance, project management, laboratory analysis, supplies). An estimated total cost for completing the

				trench of 250 ft. in length; ranged in depth from about 22 ft. to 31 ft. - Treatment system - acidification to solubilize inorganic metals, bag filtration, UV/peroxide oxidation, and neutralization			cleanup is not available at this time.
DOE DEMO Savannah River Site, Aiken, S.C. G.E. Turner, DOE Savannah River Oper. Office Environmental Restoration Div. Aiken, SC (803) 725-5178	Ground Water Pumping (Pump and Treat)	Ground water	Chlorinated Aliphatics - Trichloroethene (TCE), Tetrachloroethene (PCE), and 1,1,1-Trichloroethane (TCA) - Concentrations of volatile organic compounds (VOCs) in ground water reported as high as 500 ppm - ground water TCE concentrations over 48 ppm - ground water contains 260,000-450,000 pounds of dissolved organic solvents in concentrations greater than 0.01 ppm, estimated to be 75% TCE - Soil TCE concentrations over 10 ppm	Groundwater Extraction Wells followed by Air Stripping - 11 recovery wells at depths to over 200 feet below ground surface - Production air stripper has a design capacity of 610 gpm; operated at 510 gpm - 1993 average flow rate was 479 gpm; average air flow rate was 2,489 cfm - In 1993, 19,500 lbs of VOCs removed; average air emission rate of 2 lbs/hr			Total Capital Costs (1990 dollars) - $4,103,000 (including design, construction and installation, engineering, site development) - Total Annual Operating Costs (1990 dollars) - $149,200 (for years 1985 to 1990) (including electricity, maintenance, operation, well sampling and analysis) - Total cost of operation and maintenance is $0.75 per 1,000 gallons treated (198 million gallons per year treated) - An estimated total cost for completing the cleanup is not available at this time
FAA Technical Center, NJ Betsy Donovan (212) 637-4303	Ground Water Pumping/ Enhanced Biodegradation	Ground water	JP-4	Pump and treat followed by H2O2 addition and reinjection.	In situ		Jet fuel tank farm. Installed. Average depth of treatment approximately 15 ft.
Test Site - Hill AFB, UT 1994 R.S. Kerr Environmental Research Laboratory, U.S. EPA (405) 436-8552	Cosolvent Flushing	Ground water	BTEX, TCE, TCA, PCE, PAH				
Hazardous Waste Landfill GEO-CON, Inc	Slurry Wall	Ground water	VOCs	Containment	Bentonite alternative used because of saltwater environment		
Sanitary Landfill GEO-CON, Inc	Slurry Wall	Ground water		Limited working area			
Coal Tar Disposal Pond	Slurry Wall	Ground water	Metals and phenols	Circum- ferential containment of leachate from pond	Keyed to impervious till.		

Sources: *Innovative Treatment Technologies: Annual Status Report (Eighth and Tenth Editions, Nov. 1996 and Feb. 2001). Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America (1st and 2nd Editions, Aug 1996 and Jun 2000).*

Anniston Army Depot, AL 1999 Wayne Sisk wesisk@aec.apgea.army.mil	Biofiltration U.S. Army Environmental Center	Air	TCE				Remediation of Air Streams Contaminated with Trichloroethylene Using Biofiltration at Anniston Army Depot [fact sheet] aec.army.mil/
EPA DEMO SITE Emerging Technology Naomi Barkley (513) 569-7854	Biofiltration: "bioscrubber" (Membrane Technology and Process, Inc.)	Air	Beginning levels: 10-20 ppm Toluene Attained: > 95% removal				
EPA DEMO SITE Emerging Technology Fred Bishop (513)569-7629	Immobilized film bioreactor (gas-phase biofilter)	Air	Beginning levels: 10-1,000 ppm VOCs				
EPA Demo 1989 Ronald Lewis (513) 569-7856	Chemtact™ gaseous waste treatment	Gaseous waste streams	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 volumes of liquid condensate	Three mobile units currently available.
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 scrubber	No dioxin or furan production.
DOE Integrated Demo DOE Hanford Reservation Steve Stein (206) 528-3340	Integrated demo includes many technologies - no specific parameters given	Arid zones or environments with large vadose zones	VOCs (TCE, PCE) at arid sites				Technologies include steam reforming, supported liquid membrane separation, in situ heating, and corona destruction.
DOE Savannah River	High Energy Corona	Air	Field Scale Process				
DOE Hanford Reservation Steve Stein (206) 528-3340	Membrane Separation	Air	Beginning levels: 1000 ppm VOC Attained: 95% removal	Field Testing			$2.5M cap; $6K annual
Installation Restoration (IR) Site 9, NAS Northern Island, San Diego, CA	Zenon cross-flow pervaporation system	Groundwater	TCE concentrations were reduced on average from 200 milligrams per liter [mg/L] to less than 2 mg/L with 99% removal				
Dover AFB Maj. Mark Smith	Catalytic oxidation system	Air	TCE emissions from air strippers	Field test of various catalysts in a catalytic oxidation system			
Stamina Mills Superfund Site, N. Smithfield, RI 1999 James Kittrell 413-549-5506	Photocatalytic Destruction KSE, Inc. Amhurst, MA	Air	VOCs				AIR II Photocatalytic Technology for Air Streams [An EPA SITE Program document will be produced.]

Naval Facilities Engineering Service Center (NFESC) Port Hueneme, CA 1998 John Talley 805-982-5081	Photolytic Destruction Naval Facilities Engineering Service Center (NFESC) Port Hueneme, CA	Air	Chlorinated Solvents				Photolytic Destruction Technology for Chlorinated & Petroleum Hydrocarbons TDS-2056-ENV
Former Fire Training Area, Plattsburgh AFB, NY 1997	Flameless Thermal Oxidation Thermatrix, Inc. Knoxville, TN	Air	CAHs, TCE, PCE				"Performance and Cost Evaluation of Flameless Thermal Oxidation for Vapor-Phase VOC Treatment," Third Tri-Service Environmental Technology Workshop, 1998
Wurtsmith AFB	Oxidation	Air & Ground water	TCE		Inconjunction with Air stripping		
Former gasoline service station, Santa Monica, CA	Oxidation	Air & Ground water	BTEX		Dual extraction		
Installation Restoration (IR) Site 11, NAS Northern Island, San Diego, CA	Terra Vac pilot SVE/ Air Sparging/ Catalytic Oxidation System	Contaminated air from soil washing	Up to 250 pounds (33 gallons) per day of VOCs was effectively removed from the vadose zone and subsequently destroyed.				

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TABLE B-1 DOE SITE REMEDIATION TECHNOLOGIES BY WASTE CONTAMINANT

Technology	Media	Waste Contaminant	Description	Treatment Technology
Metals				
Arc Melter Vitrification	Soil	Toxic metals	Vitrification	Solidification/Stabilization
Bio-Immobilization of Heavy Metals	Ground water, surface water, aqueous streams	Toxic metals	Uses bacteria to transform heavy metal ions to an insoluble, less toxic form	Solidification/Stabilization
Biological Destruction of Tank Waste	Supernatants, aqueous streams	Toxic metals	Biosorption	Bioreactors
Electrokinetic Remediation of Heavy Metals and Radionuclides	Soil	Heavy metals	Electrical current is supplied between two electrodes, ions of contaminant will be attracted to one of the electrodes	Electrokinetic Separation
Encapsulation of Hazardous Wastes	Liquid, slurry, solid waste	Metals, inorganics	Encapsulation of wastes	Solidification/Stabilization
In Situ Ground Water Remediation Using Colloid Technology	Ground water	Heavy metals absorbed on clay and silica	In situ colloid immobilization of contaminants	Solidification/Stabilization
In Situ Vitrification of Contaminated Soils	Soil	Heavy metals	Immobilization	Solidification/Stabilization
Mitigation Barrier Covers	Arid soils	Soluble metals	Containment/ Treatment	Passive/Reactive Treatment Walls
Polyethylene Encapsulation of Radionuclides and Heavy Metals	Aqueous salt and concentrate, saltcake, sludge, ash, ion exchange resin in tanks	Toxic metals (e.g., Cr, Pb, Cd)	Encapsulation	Solidification/Stabilization
Remediation of Metals Contaminated Soils Using Ligand-Based Extraction Technology	Soil	Pb, Hg, Cr	Density classification followed by extraction to remove metals from soil	Separation, Chemical Extraction
Mixed Waste				
Dynamic Underground Stripping of VOCs	Soil, ground water	Mixed waste	Enhanced Removal	Thermal Treatment
Electrokinetic Remediation of Heavy Metals and Radionuclides	Soil	Heavy metals and Radionuclides	Electrical current is supplied between two electrodes, ions of contaminant will be attracted to one of the electrodes	Electrokinetic Separation

In Situ Ground Water Remediation Using Colloid Technology	Ground water	Mixed waste	In situ colloid immobilization of contaminants	Solidification/Stabilization
In Situ Vitrification of Contaminated Soils	Soil	Mixed waste	Destruction/ Immobilization	Solidification/Stabilization
Plasma Hearth Process	Soil, stored waste	Mixed waste	Waste Form Enhancement	Solidification/Stabilization
Organics				
Adsorption of BTEX Using Organozeolites	Ground water, Surface Water	Single-ring aromatics, BTEX	Adsorption of aromatic compounds	Adsorption/Absorption
Arc Melter Vitrification	Soil	Organics	Vitrification	Solidification/Stabilization
Biological Destruction of Tank Waste	Supernatants, aqueous streams	Organics	Biosorption	Bioreactors
Bioreactors for Bioremediation	Ground water	TCE, PCE, Vinyl Chloride, DCE, TCA, and BTEX	Uses a bioreactor to biodegrade unwanted chlorinated chemicals	Bioreactors
Bioremediation of High Explosives by Plants	Soil	Nitroaromatic compounds, TNT	Bioremediation	Enhanced Bioremediation
Dry Barriers for Containment and Remediation at Waste Sites	Soil	VOCs, volatile solvents, petroleum fuels	Drying of horizontal soil layer to create a barrier	Landfill Cap
Dynamic Underground Stripping of VOCs	Soil, ground water	VOCs	Enhanced Removal	Thermal Treatment
Engineered System for In Situ Bioremediation of Ground Water	Ground water	CCl_4	Micro-organisms biodegrade CCl_4 to harmless chemicals	Enhanced Biodegradation
High-Energy Corona	Gas, aqueous and non-aqueous liquids	VOCs, halogenated solvents (e.g., TCE, PCE, carbon tetrachloride, chloroform, diesel fuel, gasoline)	Destruction of VOCs at room temperature	High Energy Destruction
In Situ Air Stripping of VOCs Using Horizontal Wells	Permeable soils, ground water	VOCs, light hydrocarbons, chlorinated solvents, TCE, PCE	Enhanced Removal	Directional Wells, In-Well Air Stripping
In Situ Ground Water Remediation Using Colloid Technology	Ground water	Pesticides	In situ colloid immobilization of contaminants	Solidification/Stabilization
In Situ Vitrification of Contaminated Soils	Soil	VOCs	Destruction/ Immobilization	Solidification/Stabilization
In Well Vapor Stripping	Ground water	VOCs	Gas is bubbled through contaminated ground water to liberate contaminants	In-Well Air Stripping
Methane-Enhanced Bioremediation for the Destruction of TCE Using Horizontal Wells	Soil, ground water	Halogenated aliphatic organics, TCA, TCE, PCE	Co-metabolic Destruction	Enhanced Biodegradation

Mitigation Barrier Covers	Arid soils	VOCs, organics	Containment/ Treatment	Passive/Reactive Treatment Walls
Plasma Hearth Process	Soil, stored waste	Organics	Waste Form Enhancement	Solidification/Stabilization
Six-Phase Soil Heating	Soil	VOCs, SVOCs	Extraction	Thermal Treatment
Thermal Enhanced Vapor Extraction System	Arid soils	VOCs, SVOCs, VOC-oil mixtures, chemicals with vapor pressures <0.002atm @20°C	Extraction	Thermal Treatment
Tunable Hybrid Plasma	Air	VOCs	Organic compounds are destroyed or oxidized with an electron beam	High Energy Destruction
VOC Off-Gas Membrane Separation	Gas stream	VOCs, halogenated solvents, carbon tetrachloride, chloroform	Membrane Separation	Membrane Separation
VOC Recovery and Recycle	Air	VOCs	A Brayton cycle heat pump condenses an air stream and VOCs can be captured and re-used or disposed	Vapor Phase Carbon Adsorption
Radioactive				
Biological Destruction of Tank Waste	Supernatant aqueous streams	Various radionuclides, TRU	Biosorption	Bioreactors
Chelators for Application In Radioactive Actinide Waste Remediation	Soil, Process waste streams	Pu	Selective removal of radioactive and highly toxic actinides with organic chelators	Separation
Compact Processing Units for Radioactive Waste Treatment	Liquids, sludges, slurries	High-level, low-level, TRU	Biosorption	Ion Exchange
Cryogenic Retrieval of Buried Waste	Soil, buried waste	TRU	Freezing/ Retrieval Containment	Excavation, Retrieval, and Off-Site, Separation
Electrokinetic Remediation of Heavy Metals and Radionuclides	Soil	Radionuclides	Electrical current is supplied between two electrodes, ions of contaminant will be attracted to one of the electrodes	Electrokinetic Separation
In Situ Ground Water Remediation Using Colloid Technology	Ground water	Pu	In situ colloid immobilization of contaminants	Solidification/Stabilization
In Situ Vitrification of Contaminated Soils	Soil	Various radionuclides, TRU	Immobilization	Solidification/Stabilization
Polyethylene Encapsulation of Radionuclides and Heavy Metals	Aqueous salt and concentrate, saltcake, sludge, ash, ion	Various radionuclides, TRU	Encapsulation	Solidification/Stabilization

	exchange resin in tanks			
Remediation of Metals Contaminated Soils Using Ligand-Based Extraction Technology	Soil	U	Density classification followed by extraction to remove metals from soil	Separation, Chemical Extraction
Resorcinol-Formaldehyde Ion Exchange Resin for Cesium Removal	Cs supernatant salt streams	Cs	Ion Exchange	Ion Exchange
Selective Extraction/Leaching of Uranium from Soil	Soil, sediment	U	Attrition scrubbing and carbonate leaching remove uranium from soil	Chemical Extraction
Other or Waste Independent				
Biological Destruction of Tank Wastes	Supernatants, aqueous streams	Nitrate	Biosorption	Bioreactors
Cryogenic Retrieval of Buried Waste	Soil, buried waste	Hazardous waste	Freezing/ Retrieval Containment	Excavation, Retrieval, and Off-Site, Separation
Decision Support System To Select Migration Barrier Cover Systems	Arid and humid soils	Waste Independent	Multi-objective Decision Making Software System	Passive/Reactive Treatment Walls
Hydraulic Impact End Effector	Hard waste forms in tanks	N/A	Fracturing of solid waste forms	Fracturing
Medium-Pressure Waterjet Dislodging and Conveyance End Effector Using Confined Sluicing	Supernatant, sludge, saltcake in tanks	Waste Independent	Confined Sluicing	Excavation, Retrieval, and Off-Site
Polymer Gel as a Barrier for Ground Spill Contaminants	Soil	Applicable to many chemicals and radioactive contaminants (depending on the polymer barrier material selected).	Injection of a wall-forming fluid that gels in situ	Solidification/Stabilization
Remote Excavation System	Soil	Waste Independent	Retrieval	Excavation, Retrieval, and Off-Site
Subsurface Barrier Emplacement Development	Soil	Waste Independent	An impermeable grout barrier is placed beneath the waste to prevent further contamination	Landfill Cap

TABLE B-2 COMPLETED *SITE* DEMONSTRATION PROGRAM PROJECTS AS OF OCTOBER 1999

Developer	Technology/ Demonstration Location	Technology Contact	EPA Project Manager	Waste Media	Applicable Waste	
					Inorganic	Organic
ASC/EMR Wright Patterson AFB (010a)	Phytoremediation of TCE in groundwater, Carswell AFB Ft. Worth, TX	Greg Harvey (513) 255-7716	Steve Rock (513) 569-7149	Ground Water	Not Applicable	TCE
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	John Liskowitz (908) 739-6444	Paul dePercin (513) 569-7797	Soil, Rock, Ground Water	Not Applicable	Halogenated and Non- halogenated VOCs and SVOCs
Advanced Remediation Mixing, Inc. (formerly Chemfix Technologies, Inc.) Metaric LA (002)	Chemical Fixation/Stabilization Portable Equipment Co. Site, Clackamas OR	Sam Pizzitola (504) 461-0466	Ed Barth (513) 569-7869	Soil	Nonspecific	Not Applicable
Allied Signal Corporation, Des Plaines IL (009)	Submerged Aerobic Fixed Film Reactor, St. Joseph MI	Steve Lupton (703) 391-3500	Annette Gatchett (513) 569-7697	Ground Water	Not Applicable	Nonspecific Organics
American Combustion, Inc. Norcross, GA (001) Demonstration Date: November 1987 - January 1988	PYRETRON® Thermal Destruction/ EPA's Incineration Research Facility in Pine Bluff, AR,	Gregory Gitman (404) 564-4180	Laurel Staley (513) 569-7863	Liquids, Soil, Sludge	Not Applicable	Nonspecific Organics
Arctic Foundations, Anchorage, AK (010a)	Freeze Barrier, DOE Oak Ridge Facility, TN	Ed Yarmak (907) 562-2741	Steve Rock (513) 569-7149	Ground Water	Not Specified	Not Specified
AWD Technologies Inc., San Francisco CA (004)	Integrated In-Situ Vapor Extraction and Steam Vacuum Stripping Process, Lockheed Site Burbank CA	David Bluestein (415) 227-0822	Gordon Evans (513) 569-7684	Soil	Not Applicable	Nonspecific Organics
Babcock & Wilcox Co.[b] Lynchburg, VA (006)/ (E02) Demonstration Date: November 1991	Cyclone Furnace/ Developer's Facility in Alliance, OH	Evans Reynolds (937) 865-3334	Laurel Staley (513) 569-7863	Soil	Nonspecific, Low-Level Radionuclides, Heavy Metals	Nonspecific Organics
Bergman, USA (006) (Company no longer in business)	Sediment, Soil Washing, Saginaw Bay Confined Disposal Facility, Essexville MI	Not Available	Annette Gatchett (513) 569-7697	Sediments, Soil	Heavy Metals, Radionuclides	PCBs, Nonspecific Organics
Berkely Environmental Restoration Center, Berkeley, CA (005)	In Situ Steam Enhanced Extraction Process/ Lawrence Livermore National Laboratory in Altamont Hills, CA	Kent Udell (510) 653-9477	Paul DePercin (513) 569-7797	Soil	Not Applicable	VOCs and SVOCs, Hydrocarbons, Solvents
Billings and Associates, Inc. Albuquerque NM (007)	Subsurface Volatilization and Ventilation System (SVVS)/ Site in Buchanan, MI	Gale Billings (505) 345-1116 Austin Cooley (713) 492-1888	Paul dePercin (513) 569-7797	Soil, Sediment, Sludge	Not Applicable	BTEX, Hydrocarbons
Biotrol, Inc. Eden Prairie, MN (003) Demonstration Date: July - September 1989	BIOTROL, Biological Aqueous Treatment System/ MacGillis and Gibbs Superfund Site in New Brighton, MN	Durell Dobbins (612) 942-8032	Not Available	Liquid Waste, Ground Water	Not Applicable	Chlorinated and Non- chlorinated Hydrocarbons, Pesticides
Bio-Rem, Inc. Butler, IN (006) Demonstration Date: May 1992 - June 1993	Augmented In Situ Subsurface Bioremediation Process/ Williams AFB in Phoenix, AZ	David O. Mann (219) 868-5823	Teri Richardson (513) 569-7945	Soil, Water	Not Applicable	Halogenated and Non- halogenated Hydrocarbons
BioGenesis Enterprises, Inc. Des Plaines, IL (005) Demonstration Date: November 1992	BioGenesis[SM] Soil Washing Process/ Refinery site in Minnesota	Charles Wilde (703) 250-3442 Mohsen Amiran (708) 827-0024	Annette Gatchett (513) 569-7697	Soil, Sediment, Sludge	Nonspecific Inorganics	Volatile and Nonvolatile Hydrocarbons, PCBs, Nonspecific Organics

BioTrol, Inc. Eden Prairie, MN (003) Demonstration Date: September - October 1989	BIOTROL, Soil Washing System/ MacGillis and Gibbs Superfund Site in New Brighton, MN	Dennis Chilcote (612) 942-8032	Mary Stinson (732) 321-6683	Soil	Nonspecific Metals	High Molecular Weight Organics, PAHs, PCP, PCBs, Pesticides
Brice Environmental Services Corporation (BESCORP) Fairbanks, AK (006) Demonstration Date: September 1992	Soil Washing Process/ Alaskan Battery Enterprises Superfund Site in Fairbanks, AK	Craig Jones (907) 452-2512	John Martin (513) 569-7758	Soil	Radioactive and Heavy Metals	Hydrocarbons
Calgon Carbon Oxidation Technologies, Pittsburgh, PA (006)	Perox-pure Chemical Oxidation Technology/ Lawrence Levermore National Laboratory in Altamont Hills, CA	Bertrand Dussert (800) 422-7266	Norma Lewis (513) 569-7665	Ground Water, Wastewater	Not Applicable	Fuel Hydrocarbons, Chlorinated Solvents, PCBs, Phenolics, Pesticides
CF Systems Corporation Avada, CO (002) Demonstration Date: September 1988	Kiquified Gas Solvent Extraction (LG-SX) Technology/ New Bedford Harbor Superfund Site in New Bedford, MA	L.V. Benningfield (303) 420-1550	Laurel Staley (513) 569-7863	Soil, Sludge, Sediment, Wastewater	Not Applicable	PCBs, VOCs, SVOCs, PAHs, Dioxins, PCP
COGNIS, Inc. (009)/ (E05)	TERRAMET Soil Remediation System/ Twin Cities Army Ammunition Plant in New Brighton, MN	Lou Magdits (573) 626-3476	Michael Royer (732) 321-6633	Soil, Sludge, Sediment	Lead, Heavy Metals	Not Applicable
Commodore Environmental Services, Inc. Columbus, OH (010)	Solvated Electron Remediation System/ Construction Battalion Supply Center in Por Hueneme, CA	Carl Magnell (614) 297-0365	Paul dePercin (513) 569-7797	Soils, Sludges, Sediments, Oils, Hand Tools, Personal Protective Clothing	Not Applicable	PCBs, Pesticides, Halogenated Compounds
Commodore Advanced Sciences, Inc. (HSA) (03a)	SET Process for PCBs Naval Facility, Pearl Harbor, HI (Region 9)	Mack Jones (505) 872-6803	Thomas Holdsworth (513) 569-7675	Soil	Not Applicable	PCBs
Dehydro-Tech Corporation Hanover, NJ (004) Demonstration Date: August 1991	Solvent Extraction of Wet, Oily Waste/ EPA Research Facility in Edison, NJ	Theodore Trowbridge (908) 904-1606	Laurel Staley (513) 569-7863	Soil, Sludge, Sediments	Not Applicable	PCBs, Dioxins, PAHs, Hydrocarbon Soluble Organics
DNAPL Consortium CES Inc.	Six Phase Heating of TCE Cape Canaveral, FL (Region 4)	Eric Maxi (770) 792-1190	Thomas Holdsworth (513) 569-7675	Soil	Not Applicable	TCE
Duke Engineering (010a)	Surfactant Flushing Austin, TX	Harry Linnemeyer (512) 425-2000	Thomas Holdsworth (513) 569-7675	Soil	Nonspecific Inorganics	Nonspecific Organics
Dynaphore/Forager Sponge Richmond, VA (006)	Removal of Dissolved Metals National Lead Industries Pedricktown, NJ	Norman Rainer (804) 288-7109	Carolyn Esposito (732) 906-6895	Groundwater, Surfacewater	Nonspecific Metals	Not Applicable
E&C Williams Summervukke, SC (HSA) (02a)	Chemical Stabilization of Mercury Mining Wastes Column and humidity cell tests on waste from sulphur bank mercury mine located in Clear Lake, CA. Testing is in Butte, MT (Region 8)	Charlie Williams (843) 821-4200 Amy Anderson (888) 977-9156	Ed Bates (513) 569-7774	Soil	Heavy Metals and Nonspecific Inorganics	Not Applicable
Earthsoft, Inc. Littleton, MA (HSA) (03a)	Equis Environmental Data Management System, Trenton, NJ BROS, Superfund Site (Region 2)	Mitchell Beard (478) 486-9057	Richard Eilers (513)	Not Applicable	Not Applicable	Not Applicable
Eco Mat, Inc Hayward, CA (HSA) (02a)	Biological Denitrification Bendena Site, Bendena KS	Kim Halley (510) 783-5885	Randy Parker (513) 569-7271	Groundwater	Nonspecific Inorganics	Not Applicable
EET, Inc. Bellaire, TX (009)	PCB/Metals Extraction from Porous Surface Pearl Harbor, HI	Tim Tarrillion (713) 662-0727	Dennis Timberlake (513) 569-7547	Other	Metals	PCBs

Edenspace, Inc Reston, VA (010a)	Phytoextraction of Metal from Soil, Trenton NJ (Region 2)	Michael Blaylock	Steve Rock (513) 569-7149	Groundwater	Metals	Not Applicable
E. I. Dupont DeNemours & Co. Newark, DE & Oberlin Filter Co. Waukesha WI	Membrane Microfiltratin Palmerton Zinc Pile, Palmerton PA	Ernest Mayer (302) 774-2277	John Martin (513) 569-7758	Groundwater	Metals and Unspecified Inorganics	Not Applicable
E.I. DuPont DeNemours & 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	Ground Water, Leachate, Wastewater, Electroplating Rinsewaters	Heavy Metals, Cyanide, Uranium	Organic Particulates, Volatile Organics, Oily Wastes
ECOVA Corporation Boulder, CO (006) Demonstration Date: May - September 1991	Bioslurry Reactor/ EPA Test and Evaluation Facility in Cincinnati, OH	William Mahaffey (303) 670-2875	Ronald Lewis (513) 569-7856	Soil, Sludge, Liquids	Not Applicable	Creosote and Petroleum Wastes
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	Not Applicable	PCBs, PAHs, Chlorinated Dioxins and Dibenzo-furans, Chlorinated Solvents and Chloro- phenols
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	Not Applicable	PCBs, PAHs, Chlorinated Dioxins and Dibenzo-furans, Chlorinated Solvents and Chloro- phenols
EnviroMetal Tecnologies Inc. Guelph, Ontario, Canada (008)	In Situ and Ex Situ Metal-Enhanced Adiotic Degradation of Dissolved Halogenated Organic Compounds in Ground Water/ industrial facility, New Jersey; industrial facility, New York	William Matulewicz (609) 722-6700	Annette Gatchett (513) 569-7697	Ground Water	Not Applicable	Halogenated Organic Compounds
EPOC Water, Inc. Fresno, CA (004) Demonstration Date: May 1992	Precipitation, Microfiltration, and Sludge Dewatering/ Iron Mountain Superfund Site in Redding, CA	Scott Jackson (209) 291-8144	Annette Gatchett (513) 569-7697	Sludge, Wastewater, Leachable Soil	Heavy Metals	Nonspecific Organics
Filter Flow Technology, Inc. League City, TX (006) Demonstration Date: September 1993	Colloid Polishing Filter Method/ DOE's Rocky Flats Plant in Denver, CO	Tod Johnson (713) 334-6080	Annette Gatchett (513) 569-7697	Ground Water, Industrial Wastewater	Heavy Metals, Nontritium Radionuclides	Not Applicable
General Atomics San Diego, CA (001) Demonstration Date: March 1989	Circulating Bed Combustor/ Developer's Facility in La Jolla, CA, using waste from McColl Superfund Site in Fullerton, CA	Robert Goforth (619) 455-2499	Douglas Grosse (513) 569-7844	Soil, Sludge, Slurry, Liquids	Metals, Cyanide, Nonspecific Inorganics	Halogenated and Non- halogenated Organic Compounds, PCBs
General Environmental Cooporation, Denver, CO (008)	CURE-Electro-coagulation Wastewater Treatment System/ DOE's Rocky Flats Plant in Denver, CO	Carl Dalrymple (303) 761-6960	Steven Rock (513) 569-7149	Water	Metals and Radionuclides	Not Applicable
Geokinetics, San Fransisco, CA (HSA) 03a2	Electrokinetics for NSFO Mobilization, Naval Facility, Pearl Harbor, HI	Stephen R. Clark (510) 704-2940	Thomas Holdsworth (513) 569-7675	Soil	Nonspecific Inorganics	Not Applicable
Geosafe Corporation, Richland, WA (002)	In Situ Vitrification/ Parsons Chemical site in Grand Ledge, MI	James Hansen (509) 375-0710	Teri Richardson (513) 569-7949	Soil, Sludge, Sediments	Nonspecific Inorganics	Nonspecific Organics
GIS Solutions, Inc. Concord CA (007)	GIS/Key Software for HW Site Data Management, Westin Hotel, San Francisco CA (Region 9) and Sheraton Hotel, Washington DC (Region 3)	Garry W. Reid (510) 827-5400	Richard Eilers (513) 569-7809	Not Applicable Information Systems	Not Applicable	Not Applicable

GRACE Bioremediation Technologies, Mississauga, Ontario, Canada (008)	DARAMEND Bioremediation Technology/ Domtar Wood Preserving facility in Trenton, Ontario, Canada	LouAnn Cornacchio	Teri Richardson (513) 569-7949	Soil, Sediment, Sludge	Lead, Manganese, Zinc	PAHs, PCP, Total Petroleum Hydrocarbons
Gruppo Italimpresse 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	John Cioffi (206) 883-1900	Laurel Staley (513) 569-7863	Soil, Sediment	Not Applicable	Nonspecific Organics
High Voltage Environmental Applications, Inc. Miami, FL (008)/(E03)	High-Energy Electron Irradiation/ DOE's Savannah River site in Aiken, SC	William Cooper (305) 348-3049	Franklin Alvarez (513) 569-7631	Liquid, Sludge	Not Applicable	Most Organics
Horsehead Resource Development Co., Inc. (HRD) Palmerton, 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 (610) 826-8818	Marta Richards (513) 569-7692	Soil, Sludge, Industrial Solid Residues	Heavy Metals	Not Applicable
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 Applicable	Halogenated or Non- halogenated Volatiles or Semivolatiles
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	Not Available	Paul dePercin (513) 569-7797	Soil, Ground Water	Not Applicable	VOCs, SVOCs, Hydrocarbons, Solvents
ITRI/NUS ITRI-Chicago IL Haliburton/NUS Ridge TN	Radio-frequency Heating Kelly Air Force Base, San Antonio, Texas (Region 6)	Clifford Blanchard (615) 483-9900	Laurel Staley (513) 569-7863	Soil	Not Applicable	Nonspecific Organics
Illinois Institute of Technology Research Institute/ Brown and Root Environmental, Chicago, IL (007)	Radio Frequency Heating, Kelly AFB in San Antonio, TX	Clifton Blanchard (615) 483-9900	Laurel Staley (513) 569-7863	Soil	Not Applicable	Petroleum Hydrocarbons, VOCs, SVOCs, Pesticides
IT Corporation DNAPL Consortium	$KMnO_4$ Oxidation of TCE, Cape Canaveral, FL (Region 4)	Wendy Leonard (813) 626-2336	Thomas Holdsworth (513) 569-7675	Soil	Not Applicable	TCE
ITT Industries Roanoke, VA (HSA) (01)	Enhanced In Situ Bioremediation of Chlorinated Compounds, ITT, Night Vision Facility, Roanoke, Va (Region 3)	Rosann Kryczkowski (540) 362-7356	Vicente Gallardo (513) 569-7176	Ground Water	Not Applicable	Chlorinated Organics
International Waste Technologies, Wichita KS (001) (2)	In Situ Solidification and Deep Soil Mixing, G.E. Hialeah (Region 4)	Jeff Newton (316) 269-2660 GeoCon, Inc. Pittsburgh, PA Chris Ryan (412) 856-7700	Mary Stinson (732) 321-6683	Soil	Nonspecific Inorganics	Not Applicable
J.R. Simplot Company, Pocatello, ID (006)/ (E03)	The SABRE Process/ Bowers Field in Ellensburg, WA and Weldon Spring Ordnance Works site in Weldon Spring, MO	Russell Kaake (208) 234-5367	Wendy Davis-Hoover (513) 569-7206	Soil	Not Applicable	Nitro- aromatics
KAI Technologies, Inc./Brown and Root Environmental, Portsmouth, NH (008)	Radio Frequency Heating/ Kelly Air Force Base in San Antonio, TX	Raymond Kasevich (603) 431-2266 Captain Jeff Stinson (904) 283-6254 Clifton Blanchard (423) 483-9900	Laurel Staley (513) 569-7863	Soil	Not Applicable	Petroleum Hydrocarbons, VOCs, SVOCs, Pesticides

MACTEC Environmental, Inc. Denver, CO (010)	In Well Vapor Stripping of Ground Water, NASNI, San Diego, CA (Region 9)	Warren Schultz (303) 273-3100	Michelle Simon (513) 569-7469 Fax (513) 569-7676	Ground Water	Not Applicable	Nonspecified Organics
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	Ground Water, Wastewater	Cyanide	Halogenated Solvents, Phenol, PCP, PCBs, BTEX
Matrix Photocatalytic Inc., London, Ontario, Canada (009)/(E05)	Photocatalytic Water Treatment/ DOE's Oak Ridge Reservation in Oak Ridge, TN	Bob Henderson (519) 660-8669	Richard Eilers (513) 569-7809	Wastewater, Ground Water, Process Water	Nonspecific Inorganics	Most Organics
Maxymillian Technologies, Inc., Boston, MA (005)	Thermal Desorption System/ Niagara Mohawk Power Corporation Harbor Point site in Utica, NY	Neal Maxymillian (617) 557-6077	Ronald Lewis (513) 569-7507	Soil	Cyanide	VOCs, SVOCs, PAHs, Coal Tars
Monsanto/Dupont	In Situ Electro-osmosis of TCE in Soil/Groundwaters (Lasagna Process), Gaseous Diffusion Plant, Paducah, KY (Region 4)	Not Given	Thomas Holdsworth (513) 569-7675	Ground Water	Not Applicable	TCE
NJIT, Newark, NJ and GeoTech Development Corp., King of Prussia, PA	Cold Top Vitrification, Niagara Falls NY	William Librizzi (973) 596-5846 Thomas Tate (610) 688-4274	Marta Richards (513) 569-7692	Soil	Nonspecific Inorganics	Not Applicable
North American Technologies Aprotek, Houston, TX	Oleofilter Petroleum Products	Alan Bell (281) 398-7138	Laurel Staley (513) 569-7863	Surface Water	Not Applicable	Petroleum Hydrocarbons
NY State Bioremediation ENSR (009) (3)	Biovault Sweden-3 Chapman Site, Brockport N.Y.	Not Given	Annette Gatchett (513) 569-7697	Soil	Not Applicable	Nonspecific Organics
NOVATERRA, Inc. (formerly Toxic Treatments USA, Inc.) Los Angeles, CA (003) Demonstration Date: September 1989	In Situ Soil Treatment (Steam and Air Stripping)/ Annex Terminal, San Pedro, CA	Philip LaMori (310) 328-9433	Paul dePercin (513) 569-7797	Soil, Sludge, Liquids	Nonspecific Inorganics, Heavy Metals	VOCs, SVOCs, Hydrocarbons
OHM Remediation Services Corp., Lombard, IL (004)	X*TRAX Thermal Desorption/ Re-Solve, Inc., Superfund site in North Dartmouth, MA	Dick Ayer (803) 646-2413	Paul dePercin (513) 569-7797	Soil, Sludge, Solids	Mercury, Heavy Metals	VOCs, SVOCs, PCBs, Hydrocarbons
Phytokinetics, Inc. Logan, UT (010a)	Phytoremediation of Petroleum in soil and groundwater, Chevron Transfer Facility	Ari Ferro (801) 750-0985	Steve Rock (513) 569-7149	Soil, Ground Water	Not Applicable	Petroleum Hydrocarbons
Pintail Systems, Inc., Aurora, CO (009)	Biodegradation of Cyanide Battle Mountain, NV	Caren Caldwell (303) 307-8464	Pat Clark (513) 569-7561	Soil	Cyanide	Not Applicable
Pintail Systems, Inc., Aurora, CO (009) (2)	Biostabilization of Lead, Crooksville OH,	Leslie Thompson (303) 307-8464	Patrice Clark (513) 569-7561	Soil	Lead	Not Applicable
Pintail Systems, Inc.,	Biological Stabilization of Arsenic in Soils, Jackson, CA	Leslie Thompson (303) 307-8464	Not Given	Soil	Arsenic	Not Applicable
Praxis Environmental, Services San Francisco CA. (005)	Steam Injection/Vacuum Extraction, Hill AFB, UT	Dr. Lloyd Steward (415) 641-9044	Paul de Percin (513) 569-7797	Soil	Not Applicable	Nonspecific Organics
Regenesis San Clemente, CA (HSA) (03a)	Biological Treatment; Hydrogen Release Compound (HRC) of Organics, Rocky Mountain Arsenal, Denver, CO (Region 8)	Dr. Stephen Koenigsberg (949) 366-8000	Paul de Percin (513) 569-7797	Ground Water	Not Applicable	Nonspecific Organics
Region 8 and State of Colorado, (HSA) (02a)	Multiple Innovative Passive Mine Drainage Technologies, Summitville CO,	Victor Kettellapper (303) 312-6578	Ed Bates (513) 569-7774	Surface Water	Not Specified	Not Specified

Remediation Technologies, Inc., Seattle, WA (002)	Liquid and Solids Biological Treatment/ Niagara Mohawk Power Corporation facility at Harbor Point in Utica, NY	David Nakles (412) 826-3340	Annette Gatchett (513) 569-7697	Soil, Sediment, Sludge	Not Applicable	Biodegradable Organics, Creosote, PCP, PAHs
Resources Conservation,Co Bellevue WA	Solvent Extraction (BEST), Indiana Harbor, Gary IN	Bill Hines (206) 828-2400	Mark Meckes (513) 569-7348	Soil, Sediment	Not Applicable	Nonspecific Organics
Retech, M4 Environmental Management Inc. Ukiah, CA (002) Demonstration Date: July 1991	Plasma Arc Vitrification/ DOE Component Development and Integration Facility in Butte, MT	R.C. Eschenback (707) 462-6522	Laurel Staley (513) 569-7863	Soils, Sludge	Metals	Nonspecific Organics
Rochem Separation Systems, Inc., Torrance, CA (006)	Rochem Disc Tube Module System/ Central Landfill Superfund site in Johnston, RI	David LaMonica (310) 370-3160	Douglas Grosse (513) 569-7844	Nonspecific Liquids, Leachates	Nonspecific Inorganics	Organic Solvents
Rocky Mountain Remediation Services (HSA) (01)	Envirobond Soil Amendment (Stabilization), Roseville/Crooksville, OH Pottery Sites (Region 5)	Jim Barthel (303) 215-6620	Ed Barth (513) 569-7669	Soil	Nonspecific Inorganics	Not Applicable
Sandia National Laboratories Albuquerque, NM (009) (S)	Electrokinetic Extraction in Unsaturated Soils, Albuquerque, NM (Region 6)	Not Applicable	Randy Parker (513) 569-7271	Soil	Nonspecific Inorganics	Not Applicable
SBP Technologies Inc., Baton Rouge, LA (504) 755-7711	Membrane Filtration American Creosote Works, Pensacola FL	Not Applicable	John Martin (513) 569-7758	Soil	Not Specified	Not Specified
Sevenson, W.C. (Formerly MAECORP), Munster, IN	MAECORP Soil Stabilization, U.S. DOD Fort McCoy, Sparta, WI	Karl W. Toast (219) 836-0116	Annette Gatchett (513) 569-7697	Soil	Not Specified	Not Applicable
Smith Environmental Technologies Corporation, Englewood, CO (006)	Low Temperature Thermal Aeration (LTTA)/ Pesticide site in Phoenix, AZ	Joseph Hutton (219) 926-8651	Paul de Percin (513) 569-7797	Soil, Sludge, Sediment	Not Applicable	VOCs, SVOCs, OCPs, OPPs, TPH
SoilTech, ATP Systems, Inc. Porter IN, (005)	Thermal Desorption Dechlorination, Wide Beach, Brant NY (Region 2)	Joe Hutton (219) 926-8651	Paul de Percin (513) 569-7797	Soil	Not Applicable	Nonspecific Organics
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	Joseph Hutton (219) 926-8651	Paul dePercin (513) 569-7797	Soil, Sludge, Sediment	Mercury	Petroleum and Halogenated Hydrocarbons, PAHs, VOCs, SVOCs
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	Annette Gatchett (513) 569-7697	Soil, Sludge	Metals, Nonspecific Inorganics	Nonspecific Organics,Oil and Grease
Solucorp Saddle Brook, NJ (009)	Molecular Bonding System Midvale Slag, UT (Region 8)	Noel Spindler (914) 623-2333	Thomas Holdsworth (513) 569-7675	Soil	Nonspecific Inorganics	Not Applicable
Sonotech, Inc., Atlanta, GA (007)	Frequency- Tunable Pulse Combustion System/ EPA's Incineration Research Facility in Jefferson, AR	Ben Zinn (404) 894-3033	Marta K. Richards (513) 569-7692	Soil, Sludge, Sediment, Gas	Nonspecific Inorganics	Nonspecific Organics
Star Organics (HSA) (01)	Injection Soil Amendment (Stabilization), Roseville/Crooksville, OH, Pottery Sites (Region 5)	Phil Clarke (214) 522-0742	Ed Barth (513) 569-7669	Soil	Nonspecific Inorganics	Not Applicable
STC Remediation, A Division of Omega	Organic Stabilization and Chemical Fixation/	Stephen Pegler (480) 948-7100	Edward Bates (513) 569-7774	Soil, Sludge, Wastewater	Heavy Metals, Cyanides, Fluorides,	Nonspecific Organics, PAHs

Environmental, Inc., Scottsdale, AZ (003)	Solidification/ Selma Pressure Treating Superfund site in Selma, CA				Arsenates, Chromates, Selenium	
Terra Kleen Corporation San Diego, CA	Solvent Extraction North Island, Naval Air Station (Region 9)	Alan B. Cash (619) 522-9902	Mark Meckes (513) 569-7348	Soil, Sediment	Not Applicable	Nonspecific Organics
Terra-Kleen Response Group, Inc., Del Mar, CA (006)	Solvent Extraction Treatment System/ Naval Air Station North Island in San Diego, CA	Alan B. Cash (619) 522-9902	Mark Meckes (513) 569-7348	Soil, Sludge, Sediment	Not Applicable	PCBs, PCP, PAH, Creosote, Chlorinated, Pesticides, PCDD, PCDF
Texaco Inc., S. El Monte, CA (006)	Texaco Gasification Process/ Developer's Montebello Research Laboratory using a mixture of soil form the Purity Oil Sales Superfund site in Fresno, CA	Tim Leininger (562) 699-0948	Marta K. Richards (513) 569-7692	Soil, Sludge, Sediment	Nonspecific Inorganics	Nonspecific Organics
Toronto Harbour Commission Toronto, Ontario, Canada (007) Demonstration Date: April - May 1992	Soil Recycling/ Toronto Port Industrial District in Toronto, Ontario	Dennis Lang (416) 863-2407	Teri Richardson (513) 569-7949	Soil	Nonspecific Inorganics	Nonspecific Organics
U.S. EPA Mobile Volume Reduction Unit, Cincinnati, OH (007)	Soil Washing Escanbia Wood Preserving Site, Pensacola FL, (Region 4)	Richard Griffith (908) 321-6629	Teri Richardson (513) 569-7949	Soil	Not Specified	Not Specified
U.S. EPA San Francisco, CA (Region 9)	Excavation and Foam Suppression of Volatiles, McColl Superfund Site, Fullerton CA	John Blevins (415) 744-2400	Annette Gatchett (513) 569-7697	Air	Not Applicable	Nonspecific Organics
U.S. EPA NRMRL, Cincinnati, OH	Bioventing (air-injection), St. Louis, MN (Region 5)	Paul McCauley (513) 569-7444	Paul McCauley (513) 569-7444	Air	Not Applicable	Nonspecific Organics
U.S. EPA/NRMRL, Cincinnati OH, IT Corporation (004)	Debris Washing System, Hopkinsville, Chickamuga, GA; and Detroit MI (Region 4 & 5)	Majid Dosani (513) 782-4700 Lincensee: Process Dev. Inc. Cliff Black (937) 222-0250	John Martin (513) 569-7758	Other	Not Specified	Not Specified
U.S. EPA/NRMRL, Cincinnati OH, (005)	Hydraulic Fracturing Chicago, IL & Dayton OH (Region 5)	William Slack (513) 556-2526	Michael Roulier (513) 569-7796	Soil	Not Specified	Not Specified
U.S. EPA/NRMRL, Cincinnati, OH (005)	Base-Catalyzed Destruction (Dehalogenation), Koppers Site, Morrisville NC (Region 4)	George Huffman (513) 569-7341 Environmental Inc. Blue Bell PA Yei-Shong Shieh (215) 832-0700	Terry Lyons (513) 569-7589	Soil	Not Applicable	Chlorinated Hydrocarbons
U.S. EPA/NRMRL USDA-Forest Products Lab Madison, WI	Fungus Treatment Technology Brookhaven Wood Preserving, Brookhaven MS (Region 4)	Richard Lamar (608) 231-9469	Teri Richardson (513) 569-7949	Soil	Not Applicable	Nonspecific Organics
U.S. Filter/Zimpro, Inc., Huntington Beach, CA (003)	Ultraviolet Radiation and Oxidation/ Lorentz Barrel and Drum Company site in San Jose, CA	William Himebaugh (714) 545-5557	Norma Lewis (513) 569-7665	Ground Water, Leachate, Wastewater	Not Applicable	Halogenated Solvents, VOCs, Pesticides, PCBs, BTEX, PCP
University of Nebraska-Lincoln, Lincoln, NE (010)	Center Pivot Spray Irrigation System/ North Landfill Subsite in Hasitngs, NE	Roy Spalding (402) 783-3931	Teri Richardson (513) 569-7949	Ground Water	Not Applicable	VOCs
WASTECH Inc. Oak Ridge, TN (004) Demonstration Date: August 1991	Solidification and Stabilization/ Robins AFB in Warner Robins, GA	E. Benjamin Peacock (615) 483-6515	Terrence Lyons (513) 569-7589	Soil, Sludge, Liquid Waste	Nonspecific Radioactive Inorganics	Nonspecific Organics
Wheelabrator Clean Air Systems, Inc.,	Evaporation and Chemical Oxidation,	Bob Hernquist (708) 706-6900	Randy Parker (513) 569-7271	Wastewater, Leachate, Ground	Metals, Volatile Inorganic	VOCs and Nonvolatile

Schaumburg, IL (005)	Lake Charles, LA (Region 6)			Water, Low-Level Radioactive Mixed Waste	Compounds, Radionuclides	Organic Compounds
Xerox Corporation, Webster, NY (009)	2-PHASE EXTRACTION Process/ McClellan Air Force Base in Sacramento, CA	Ron Hess (716) 422-3694	Paul dePercin (513) 569-7797	Ground Water, Soil, Liquid	Nonspecific Soluble Inorganics	VOCs
ZENON Environmental Inc., Burlington, Ontario, Canada (007)	Bioreactor Integrated with and Ultrafiltration Membrane System, Nascoilte Site, Milvile, NJ (Region 2)	Lisa Ashton (905) 639-6320 ext.244	Dan Sullivan (732) 321-6677	Ground Water	Not Applicable	Nonspecific Hydrocarbons
ZENON Environmental Inc., Burlington, Ontario, Canada (007)	Cross Flow Pervaporation System for Removal of VOCs from Ground Water, North Island NAS Site 9, San Diego CA (Region 9)	Philip Canning 63-1-416-639-6320	Lee Vane (513) 569-7799	Ground Water,	Not Applicable	VOCs

[a] Solicitation Number.

[b] From Emerging Technology Program.

Source: EPA, 1997. Superfund Innovative Technology Evaluation Program, Technology Profiles, Ninth Edition, EPA CRD, EPA/540/R-97/502.

Performance
Data

Table C-2: Summary Table of Federal Databases

Name	Objective	Data/Technology Information	Hardware Software	Contacts
Bioremediation in the Field Search System (BFSS)	The Bioremediation in the Field Search System (BFSS) provides access to database of information on waste sites across the country where bioremediation is being tested or implemented or has been completed. BFSS users can search the database electronically, view data on specific types of bioremediation sites, and print reports of selected information.	BFSS currently provides information on ex situ and in situ technologies at more than 450 bioremediation sites nationwide. The database includes full-scale remediation efforts and treatability studies that cover sites under EPA's CERCLA, RCRA, TSCA, and UST authority.	BFSS requires an IBM-compatible PC with at least 640K of memory and MS-DOS 3.3 or higher.	BFSS is available on diskette free o charge from EPA's Center for Environmental Research Information (CERI). Please call 513-569-756 to request a copy
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.	CLU-IN is also accessible on EPA/Hazardous Waste Clean-Up home page via World Wide Wel http://clu-in.org/
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.	Contact DENIX
Defense RDT & E Online System (DROLS)	This bibliographic data base provides information on	The system provides access to three separate data bases:	The system is available through dial-up to the Defense	The DROLS homepage

	DOD's ongoing research and technology efforts.	Research Work Unit Information System, Technical Report Data Base, and Independent Research and Development Data Base.	Technical Information Center's central 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.	ITIS DOE Office of Science and Technical Information 615-576-1222 DIALOG Information Services 800-334-2564
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.	Dan Hitchcock DOE Washington, DC 20585-0002 (301) 903-6767
Global Network of Environment & Technology (GNET)	GNET was created to promote the commercialization of innovative environmental technologies. decision-makers and facilitating development of the national environmental technology strategy.	GNET features Environment & Technology NewsBriefs, Environment & Technology Business Forum, and Environment & Technology Information.	Internet access (with Net browsers such as Netscape, Mosaic, or Chameleon).	GNET Client Services 7010 Little River Turnpike Suite 430 Annandale, VA 22001 703-750-6401 703-750-6506 (fax)
Hazardous Waste Superfund Collection Data Base	This online bibliographic data base corresponds to 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	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,	Felice Sacks EPA Headquarter Library 202-260-3021

		non-government books.	and communications software.	
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.	National Technical Information Service U.S. Dept. of Commerce 703-487-4650
New Technology from DOE (NTD)	This system is designed to disseminate information about DOE research results that have potential for commercialization.	The system includes technology descriptions, patent status, secondary applications, literature citations, and DOE information.	The data base is available to DOE users with a computer, modem, and communications software capable of VT-100 emulation.	Integrated Technical Information System 615-576-1222
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.	ProTech Contact: David Biancosino (DOE-HQ) 301-903-7961 Technology Catalogue Contact: Joe Paladino (DOE-HQ) 301-903-7449
Records of Decision System (RODS)	This system provides comprehensive information on Superfund Records	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.	The EPA provide online access to RODS data.

	of Decision for Hazardous Waste cleanup sites nationwide.			
ReOpt: Electronic Encyclopedia of Remedial Action Options	The system provides information collected from EPA, DOE, and other sources about remedial action technologies.	The system contains diagrams, descriptions, engineering or design parameters, contaminants treated, technical and regulatory constraints, and other information for about 90 technologies.	The system runs on IBM-PC 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.	Janet Bryant Battelle Pacific Northwest Labs 509-375-3765
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.	Kelly J. Dwyer DOE 615-576-9374 DIALOG Information Services 800-334-2564
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.	Glenn M. Shaul EPA/RREL 513-569-7408
Soil Transport and Fate Data Base and Model Management System	The data base provides information on chemical properties, toxicity, transformation, and bioaccumulation for hundreds of	The data base includes information on approximately 400 chemicals as well as models for predicting the fate and transport of	The data base will run on any IBM-compatible computer with 640K RAM, 12.5 MB of hard disk storage, and a math coprocessor.	David S. Burden EPA/RSKERL 405-332-8800

	chemical compounds.	hazardous organic constituents in the vadose zone.		
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 Novell local area network at DOE.	Lise Wachter HAZWRAP 615-435-3281

Table C-3: Summary of Federal Site Remediation Technology Programs and Initiatives

Program Title/ Participating Agencies	Description	Assistance Available	Program Emphasis/ Restrictions	Contact
National Environmental Technology Test Site Program/U.S. DoD, EPA	An interagency effort to establish a coordinated environmental technology testing and evaluation program. The Program currently supports testing and evaluation programs at six Centers: the Air Force's Groundwater Remediation Field Laboratory (GRFL) and Chlorinated Hydrocarbon Remedial Demonstration Site (CHRDS); the Army's Environmental Technology Evaluation Center; the Navy's Environmental Technology Demonstration Site for Advanced Fuel Hydrocarbon Remediation Technologies; and the EPA's National Center for Integrated Bioremediation Research and Development (NCIBRD) and Consortium for Site Characterization Technology (CSCT).	Each Center provides locations for demonstrations, testing, and evaluation of technologies of interest to the agencies.	The name of each Center indicates the type of contaminant and media that candidate technologies should address. The GRFL focuses on technologies that treat DNAPLs. The Army Center provides testing facilities for physical, chemical, and biological remedial technologies. The NCIBRD supports the design and engineering of integrated bioremediation systems. The CSCT focuses on monitoring, measurement, and site characterization technologies.	**GRFL:** Mark Noll (302) 678-8284 **CHRDS:** Bud Hoda (916) 643-1742 **Army:** Albert Walker (410) 612-6858 **Navy:** Ernest Lory (805) 982-1299 **NCIBRD:** Mike Barcelona (313) 763-6512 **CSCT:** Eric Koglin (702) 798-2432
Rapid Commercialization Initiative	The Rapid Commercialization Initiative (RCI), an interagency effort coordinated by the U.S. Department of Commerce, fosters cooperative interaction of the private sector, states, and Federal agencies to help bring environmental technologies to market more rapidly and efficiently. RCI acts as a gateway to other federal agency programs that provide opportunities for environmental technology demonstration, verification, and transfer.	In-kind assistance for selected companies with commercial-ready environmental technologies in four categories: avoidance; control; monitoring and assessment; and remediation and restoration.	Selection of participants centers on two criteria: 1) The technology addresses environmental and market needs, with a focus on solutions to private sector needs and added consideration for application to public sector environmental problems; 2) there is a clear path to commercialization and the technology is only a few steps from commercialization, such that testing and verification will complete the process. Marketing, financing, or production assistance are not available. Exemptions from federal statutes and regulations are not available.	**U.S. DOC** Stanley Chanesman (202) 482-0825
Remediation Technologies Development Forum/U.S. EPA, DoD, DOE, other agencies	RTDF identifies ways for federal agencies to work together through partnerships with industry and academia to solve complex hazardous waste remediation problems through development of hazardous waste	EPA provides funding for RTDF research activities and Action Team meetings. Participants in each Action	The RTDF is open to all interested parties and includes partners from industry, government agencies, and academia.	**U.S. EPA** Robert Olexsey (513) 569-7861 Walter Kovalick (703) 603-9910

	characterization and treatment technologies. RTDF partners form self-managed Action Teams to undertake research, development, demonstration, and evaluation efforts to achieve common cleanup goals.	Team provide funding and/or in-kind support for the Team research efforts.		
Small Business Innovative Research Program	A multi-media assistance program designed to assist and promote small U.S.-owned high technology companies.	3-step program for grants and contracts. Phase I supports feasibility studies. Phase II supports general R&D. Phase III funds are provided through commercial sales or other funds from a Federal agency.	SBIR grants and contracts are solicited through 11 Federal agencies. Annual solicitations target U.S.-owned high technology companies with 500 or fewer employees.	**U.S. EPA** Donald Carey (202) 260-7899 **U.S. DOE** Samuel Barish (301) 903-3054 **U.S. DoD** Jon Baron (703) 697-1689
Strategic Environmental Research and Development Program/U.S. DoD, EPA, other federal agencies	SERDP is a multi-agency program funded through the Department of Defense that identifies, develops, demonstrates, and transitions technology for six thrust areas, including cleanup. The cleanup thrust area focuses on programs for conducting technology research and development.	SERDP sponsors and funds a variety of other technology development programs and activities such as the National Environmental Technology Test Sites Program.	SERDP responds primarily to environmental requirements of DoD, along with those it shares with the Department of Energy, the Environmental Protection Agency, and other federal government agencies.	**SERDP Program Office** Dr. Olufemi Ayorinde (703) 696-2118
Industry and University Program Areas	Identifies and supports development of technologies that show promise in addressing specific DOE remediation needs, and to ensure that private industry, other agencies, and universities all participate in the development and use of new and emerging technologies.	PRDAs, ROAs, CRADAs, grants, and inter-agency agreements (IAGs).	The goal of the Area is to promote private sector capability to provide needed environmental cleanup technologies to meet DOE needs and enhance the economic viability and competitiveness of the U.S. environmental industry.	**U.S. DOE** Jeffrey Walker (301) 903-7966
Program Research and Development Announcements	One of DOE's major assistance vehicles for developing technologies as part of DOE's national research, development, demonstration, testing, and evaluation program that provides environmental restoration and waste management technologies to DOE sites and to manage DOE generated waste.	PRDAs solicit a broad mix of proposals where R&D is required within broadly defined areas of interest.	Multiple awards for proposals, which may have varied approaches or concepts, are generally made. A PRDA may be issued in response to an individual program need such as the cleanup of a particular contaminant at a specific site.	**EM Central Point of Contact** (800) 845-2096
Research Opportunity Announcements	One of DOE's assistance vehicles for developing technologies as part of DOE's national research,	ROAs solicit proposals for contracts in applied research	A proposed technology should correspond to a DOE need and improve DOE's capabilities in areas such as *in situ*	**EM Central Point of Contact** (800) 845-2096

	development, demonstration, testing, and evaluation program that provides environmental restoration and waste management technologies to DOE sites and to manage DOE generated waste.	for technology development with application to DOE environmental restoration efforts.	remediation; detection, characterization, and monitoring; separation of radioactive waste; and robotics.	
Small Business Technology Transfer Pilot Program	Identifies opportunities to support innovative technology development by small businesses.	The Program includes workshops and counseling for small businesses to provide information on specific business opportunities.	Support and counseling are available to small, disadvantaged, or minority businesses and provide access to procurement offices at DOE sites.	**U.S. DOE** Joseph Paladino (301) 903-7449
Environmental Technology Initiative	Promotes the development, commercialization, and use of environmental technology to improve environmental quality while fostering new job and business creation.	Technical assistance and direct funding through an annual Program Solicitation Package.	Focus areas, specific selection criteria, and project evaluation criteria for the project-year are described in the annual Solicitation Package.	**U.S. EPA** Brendan Doyle (202) 260-2693
Environmental Technology Verification	Seeks to accelerate the entrance of new environmental technologies into the domestic and international marketplace by providing purchasers and permitters with credible cost and performance data provided by disinterested third parties. The program supports and oversees testing and verification centers covering major classes of environmental technology.	Stakeholder groups, comprised of technology buyers, sellers, and enablers are the principal customers of the program. EPA, the testing centers, and vendors will fund the program.	The goal of the ETV program is to create testing and verification processes that will provide technology buyers and enablers (permitters, etc.) with credible cost and performance data from testing and verification centers. The program is open to all environmental technologies.	**U.S. EPA** Penelope Hansen (202) 260-5735
Superfund Innovative Technology Evaluation Program	Promotes the development and use of innovative technologies to remediate Superfund sites through demonstrating technologies, including support for bench-scale through pilot-scale and field-scale demonstrations, and includes reports of cost and performance data. The Program has 3 major components: a Demonstration Program; an Emerging Technology Program; and a Monitoring and Measurement Technologies Program.	Demonstration Program costs are split between a vendor and EPA.	The Demonstration Program is open to all remediation technologies. The Emerging Technology Program supports testing and development of innovative treatment technologies. The Monitoring and Measurement Technologies Program supports innovative detection, monitoring, and measurement technologies.	**U.S. EPA** Annette Gatchette (513) 569-7696

Source: FRTR's "***Accessing the Federal Government: Site Remediation Technology Programs and Initiatives (First Edition)***", July 1996, EPA/542/B-95/006.

TABLE D-1: SUGGESTED PARAMETERS TO DOCUMENT FULL-SCALE TECHNOLOGY APPLICATIONS: MATRIX CHARACTERISTICS AFFECTING TREATMENT COST OR PERFORMANCE

	Soil Types		Aggregate Soil Properties						Organics			Other
	Soil Classification	Clay Content and/or Particle Size Dist.	Hydraulic Conduct./ Water Permeability	Moisture Content	Air Permeability	pH	Porosity	Transmissivity	Total Organic Carbon	Oil & Grease or TPH	Nonaqueous Phase Liquids	Miscellaneous
In Situ Soil Remediation												
Bioventing	X	X		X	X	X	X		X		X	
Soil Flushing	X	X	X			X			X	X	X	
Soil Vapor Extraction	X	X		X	X		X		X		X	
Ex Situ Soil Remediation												
Composting	X	X				X						
Landfarming	X	X				X						[b]
Slurry Phase Biol. Treat.	X	X										
Soil Washing	X	X							X			[b]
Solidification/Stabilization	X	X		X		X			X	X		[b]
Thermal Desorption	X	X		X						X		
Incineration	X	X		X					X			[b]
Ground Water Remediation												
Enhanced Bioremediation	X	X	X			X		X	X		X	
Air Sparging	X	X	X				X				X	
Ground Water Pumping[a]	X	X	X					X		X	X	

[a]Matrix characteristics shown for pump and treat are for ground water pumping/extraction. Treatment process selection may affect the list of desirable characteristics to be documented.

[b]Miscellaneous matrix characteristics include field capacity for land treatment; cation exchange capacity for soil washing of metal-containing wastes; Btu value, halogen content, and metal content for incineration; and bulk density and Lower Explosive Limit for thermal desorption.

TABLE D-2: SUGGESTED PARAMETERS TO DOCUMENT FULL-SCALE TECHNOLOGY APPLICATIONS: OPERATING PARAMETERS AFFECTING TREATMENT COST OR PERFORMANCE

	System Parameter										Biological Activity						
	Air Flow Rate	Mixing Rate/ Frequency	Moisture Content	Operating Pressure/ Vacuum	pH	Pumping Rate	Residence Time	System Throughput	Temperature	Wash Fluid/ Solution Components/Additives and Dosage	Biomass Concentration	Microbial Activity	Oxygen Uptake Rate	CO_2 Evolution	Hydrocarbon Degradation	Nutrients/Other Soil Amendments	Soil Loading Rate
In Situ Soil Remediation																	
Bioventing	X		X	X					X				X	X	X	X	
Soil Flushing					X	X				X							
Soil Vapor Extraction	X			X													
Ex Situ Soil Remediation																	
Land Treatment		X	X		X		X		X						X	X	
Composting	X	X	X		X		X		X				X		X	X	X
Slurry Phase Bioremediation	X	X	X		X		X	X	X		X				X	X	
Soil Washing					X			X		X							
Thermal Desorption							X	X	X								
Incineration	X						X	X	X								
Stabilization*see footnote at bottom									X								
Ground Water Remediation																	
In Situ Bioremediation	X				X						X					X	
Air Sparging	X			X													
Ground Water Pumping						X											

*Additional operating parameters for stabilization include additives and dosage, curing time, compressive strength, volume increase, bulk density, and permeability.

TABLE D-3: MATRIX CHARACTERISTICS: MEASUREMENT PROCEDURES AND POTENTIAL EFFECTS ON TREATMENT COST OR PERFORMANCE

Matrix Characteristics	Measurement Procedures	Important to Document Procedure?	Potential Effects or Cost Performance
Soil Types portion of table now presented:			
Soil Classification	Soil classification is a semi-empirical measurement of sand, silt, clay, gravel, and loam content. Several soil classification schemes are in use and include the ASTM Standard D 2488-90, Practice for Description and Identification of Soils (Visual-Manual Procedure), and the USDA and CSSC systems.	Yes	Soil classification is an important characteristic for assessing the effect on cost or performance of all technologies shown on Table D-1. For example, in soil vapor extraction, sandy soils are typically more amenable to treatment than clayey soils. (See related information under clay content and/or particle size distribution.)
Clay Content and/or Particle Size Distribution	Clay content and/or particle size distribution is measured using a variety of soil classification systems, including ASTM D 2488-90 under soil classification.	Yes	Clay and particle size distribution affect air and fluid flow through contaminated media. In slurry phase bioremediation systems, particle size affects ability to hold media in suspension. In soil washing, the particle size/contaminant concentration relationship affects potential for physical separation and volume reduction. For thermal desorption systems, clay and particle size affects mass and heat transfer, including agglomeration and carryover to air pollution control devices.
Aggregate Soil Properties portion of table now presented:			
Hydraulic	Hydraulic	Yes	This characteristic is

Conductivity /Water Permeability	conductivity/water permeability can be determined through several procedures. Hydraulic conductivity, which is a measure of the ease of water flow through soil, is typically calculated as a function of permeability or transmissivity. ASTM D 5126-90, Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone, is a guide for determining hydraulic conductivity. Water permeability is often calculated by pumping out ground water, measuring ground water draw-down rates and recharge times through surrounding monitoring wells, and factoring in the distance between the wells and the pump. Method 9100 in EPA SW-846 is used to measure permeability, as well as several ASTM standards: D 2434-68 (1974), Test Method for Permeability of Granular Soils (Constant Head); D 4630-86, Test Method for Determining Transmissivity and Storativity of Low Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test; and D 4631-86, Test Method for Determining Transmissivity and Storativity of Low Permeability Rocks by	important in ground water remediation technologies including in situ ground water bioremediation, ground water sparging, and pump and treat systems. Hydraulic conductivity and water permeability affect the zone of influence of the extraction wells and, therefore, affect the number of wells needed for the remediation effort and the cost of operating the extraction wells.

	In Situ Measurements Using the Pressure Pulse Technique.		
Moisture Content	Procedures for measuring soil moisture content are relatively standardized. Soil moisture content is typically measured using a gravimetric ASTM standard, D 2216-90, Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock.	No	The moisture content of the matrix typically affects the performance, both directly and indirectly, of technologies including soil vapor extraction, and ex situ technologies such as stabilization, incineration, and thermal desorption. For example, air flow rates during operation of soil vapor extraction technologies are affected by moisture content of the soil. Thermal input requirements and air handling systems for incineration and desorption technologies can also be affected by soil moisture content. (Effects of moisture content on operation of technologies are discussed in Table D-4).
Air Permeability	Air permeability is a measure of the ease of air flow through soil and is a calculated value. For example, air permeability may be calculated by applying a vacuum to soil with a pump, measuring vacuum pressures in surrounding monitoring wells, and fitting the results to a correlation derived by Johnson et al., 1990.	Yes	This characteristic is important for in situ soil remediation technologies that involve venting or extraction. Air permeability affects the zone of influence of the extraction wells, and, therefore, affects the number of extraction wells needed for the remediation effort and the cost of operating the extraction wells.
pH	pH is a measure of the degree of acidity or alkalinity of a matrix. Procedures for	No	The pH of the matrix can impact the solubility of contaminants and biological activity.

	measuring and reporting pH are standardized and include EPA SW-846 Method 9045 and ASTM methods for soil (ASTM D 4972-89, Test Method for pH of Soils) and ground water (ASTM D 1293-84).		Therefore, this characteristic can affect technologies such as soil bioventing, soil flushing, land treatment and composting and in situ ground water bioremediation. pH can also affect the operation of treatment technologies (see Table D-4). pH in the corrosive range (e.g., <2 and >12) can damage equipment and typically requires use of personal protection equipment and other special handling procedures.
Porosity	Porosity is the volume of air- or water-filled voids in a mass of soil. Procedures for measuring and reporting porosity are standardized. Porosity is measured by ASTM D 4404-84, Test Method for Determination of the Pore Volume and Pore Volume Distribution of Soil and Rock by Mercury Intrusion Porosimetry	No	This characteristic is important for in situ technologies, such as soil bioventing, soil vapor extraction, and ground water sparging, that rely upon use of a driving force for transferring contaminants into an aqueous or air-filled space. Porosity affects the driving force and thus the performance that may be achieved by these technologies.
Transmissivity	Transmissivity, the flow from a saturated aquifer, is the product of hydraulic conductivity and aquifer thickness.	No - The measurement of hydraulic conductivity is important to document, because transmissivity is a product of hydraulic conductivity and aquifer thickness, it would not be necessary to document the measurement procedure for this characteristic.	This characteristic is important for ground water pump and treat systems. Transmissivity affects the zone of influence in this type of remediation, which impacts the number of wells and the cost of operating the wells.
Organics portion of table now presented:			
Total Organic Carbon	TOC is a measure of the	No	TOC affects the

(TOC)	total organic carbon content of a matrix. Measurement of TOC is standardized (e.g., Method 9060 in EPA SW-846)		desorption of contaminants from soil and impacts in situ soil remediation, soil washing, and in situ ground water bioremediation.
Oil & Grease (O&G) or Total Petroleum Hydrocarbons (TPH)	Procedures for measuring O&G and TPH are standardized. O&G is measured using Method 9070 in EPA SW-846, and TPH is measured using Method 9073. A TPH analysis is similar to an O&G analysis with an additional extraction step. TPH does not include nonpetroleum fractions, such as animal fats and humic and fulvic acids.	No	O&G and TPH affect the desorption of contaminants from soil. For thermal desorption, elevated levels of TPH may result in agglomeration of soil particles, resulting in longer residence times.
Nonaqueous Phase Liquids (NAPLs)	There is no standard measurement method for determining the presence of NAPLs; rather, their presence is determined by examining ground water and identifying a separate phase. The presence of NAPLs is reported as either being present or not present.	Yes	NAPLs may be a continuing source of contaminants for in situ technologies. NAPLs may lead to increased contaminant loads and thus to greater costs or longer operating periods for achieving cleanup goals.

TABLE D-4: OPERATING PARAMETERS: MEASUREMENT PROCEDURES AND POTENTIAL EFFECTS ON TREATMENT COST OR PERFORMANCE

Operating Parameters	Measurement Procedures	Documentation Required as a Result of Method Variability?	Potential Effects on Cost or Performance
System Parameters portion of table now follows:			
Air Flow Rate	The air flow rate is a parameter set for a vapor extraction or treatment system. The measurement of air flow rate is standardized (i.e., measured with flow meters).	No	Air flow rate affects the rate of volatilization of contaminants in technologies that rely on transferring contaminants from a soil or aqueous matrix to air, such as soil bioventing, soil vapor extraction, and ground water sparging. For technologies involving oxidation processes, this parameter affects the availability of oxygen and the rate at which oxidation occurs (e.g., for biotreatment or incineration processes).
Mixing Rate/ Frequency	Mixing rate or frequency is the rate of tilling for land treatment, the rate of turning for composting, and the rotational frequency of a mixer for slurry phase bioremediation.	No	The mixing rate affects the rate of biological activity (through increased contact between oxygen and contaminants) and volatilization of contaminants.
Moisture Content	Procedures for measuring soil moisture content are relatively standardized. Soil moisture content is typically measured using a gravimetric ASTM standard: D 2216-90, Test Method for Laboratory Determination of Water (Moisture) Content of	No	The moisture content affects the rate of biological activity in soil bioventing, land treatment, composting, and slurry phase bioremediation technologies. Contaminants must be in an aqueous phase for biodegradation to occur, and water is typically

	Soil and Rock. Moisture content as a treatment system operating parameter characterizes the amount of water and aqueous reagent added to the soil (for example, moisture content for slurry phase bioremediation refers to the solid to liquid ratio).		added to a soil to maintain a sufficient level of moisture to support biodegradation.
Operating Pressure/Vacuum	Operating pressure or vacuum is measured using a pressure or vacuum gauge, such as a manometer. The measurement of this parameter is relatively standardized.	No	Operating pressure/vacuum affects the rate of volatilization of contaminants in technologies that rely on transferring contaminants from a soil or aqueous matrix to air, such as soil bioventing, soil vapor extraction, and ground water sparging.
pH	Procedures for measuring and reporting pH are standardized (e.g., Method 9045 in EPA SW-846). The pH of soil and ground water is adjusted during ex situ treatment as an operating parameter by the addition of acidic and alkaline reagents.	No	pH affects the operation of technologies that involve chemical or biological processes, such as soil flushing, soil washing, and bioremediation processes. For example, in soil washing, contaminants are extracted from a matrix at specified pH ranges based on the solubility of the contaminant at that pH.
Pumping Rate	Pumping rate is the volume of ground water extracted from the subsurface. The pumping rate is measured through a production well or treatment system using a flow meter or a bucket and stopwatch.	No	Pumping rate affects the amount of time required to remediate a contaminated area, and is important for technologies that involve extraction of ground water, such as soil flushing, and pump and treat.
Residence Time	Residence time is the	No	Residence time is

	amount of time that a unit of material is processed in a treatment system. Residence time is measured by monitoring the length of time that a unit of soil is contained in the treatment system.		important for ex situ technologies, such as land treatment, composting, slurry-phase soil bioremediation, incineration, and thermal desorption, to measure the amount of time during which treatment occurs.
System Throughput	System throughput is the amount of material that is processed in a treatment system per unit of time.	No	System throughput affects the costs for capital equipment required for a remediation and operating labor for ex situ technologies such as slurry phase soil bioremediation, soil washing, incineration, and thermal desorption.
Temperature	Temperature is measured using a thermometer or thermocouple.	No	For bioremediation technologies, temperature affects rate of biological activity. For stabilization, incineration, and thermal desorption, temperature affects the physical properties and rate of chemical reactions of soil and contaminants.
Washing/Flushing Solution Components/ Additives and Dosage	The components and dosages of washing and flushing solutions are site- and waste-specific "recipes" of polymers, flocculants, and coagulants. The type and concentrations of additives for a particular treatment application are determined based on site and waste characterization, treatability and performance tests, and operator experience. The	No	For soil flushing and washing technologies, the types and dosages of additives affects the solubility and rate of extraction for contaminants; and thus affects the costs for constructing and operating flushing and washing equipment.

	actual amounts added are measured based on the volume and concentration of additive solutions metered into the treatment system.		
Biological Activity portion of table now follows:			
Biomass Concentration	Biomass concentration is the number of microorganisms per unit volume in a treated or untreated aqueous matrix. Biomass concentrations are typically measured by direct plate counts. Portable water test kits are available for field tests. Methods 10200 through 10400 from Standard Methods for the Examination of Water and Wastewater are used in laboratory analyses of biomass concentration.	Yes	Biomass concentration is an important parameter for slurry phase soil bioremediation and in situ ground water biodegradation. Biomass is necessary to effect treatment and thus the concentration of biomass is directly related to performance.
Microbial Activity Oxygen Uptake Rate (OUR) Carbon Dioxide Evolution Hydrocarbon Degradation	Oxygen uptake, carbon dioxide evolution, and hydrocarbon degradation are all used to measure the rate of biodegradation in a treatment system. Oxygen uptake is measured using ASTM D 4478-85, Standard Test Methods for Oxygen Uptake. Carbon dioxide evolution is measured with a carbon dioxide monitor. Hydrocarbon degradation is measured by sampling the influent to and effluent from the treatment system and analyzing samples for organic constituents, such as total petroleum	Yes	Microbial activity is an important parameter for soil bioventing, land treatment, composting, and slurry phase soil bioremediation technologies. Hydrocarbon degradation is commonly used as an indicator of treatment performance for these technologies, while OUR and carbon dioxide evolution are used in specific applications to supplement the hydrocarbon degradation data.

	hydrocarbons (EPA SW-846 Method 9073).		
Nutrients and Other Soil Amendments	Nutrients usually consist of nitrogen and phosphorus (and trace inorganic constituents such as calcium and magnesium), and are typically reported as a ratio of carbon to nitrogen to phosphorus. Carbon is measured as total organic carbon, with EPA SW-846 Method 9060. Nitrogen is measured as both ammonia nitrogen using ASTM D 1426-89, Test Methods for Ammonia Nitrogen in Water, and as nitrite-nitrate using ASTM D 3867-90, Test Method for Nitrite-Nitrate in Water. Phosphorus is measured using ASTM D 515-88, Test Methods for Phosphorus in Water. Calcium and magnesium are measured using ASTM D 511-88, Test Method for Calcium and Magnesium in Water. Other soil amendments may include bulking agents for composting (e.g., sawdust).	Yes	Nutrients and other soil amendments can affect soil bioventing and in situ ground water biodegradation as this parameter directly affects the rate of biological activity and, therefore, contaminant biodegradation. This is also applicable to ex situ soil remediation technologies such as land treatment, composting, and slurry phase soil bioremediation.
Soil Loading Rate	Soil loading rate is the amount of soil applied to a unit area of a composting system.	No	The soil loading rate affects the rate of biological activity and can impact the costs for operation

FRTR
Remediation Technologies Screening Matrix and Reference Guide, Version 4.0

Appendix E Description of Source Documents

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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)	Environmental Quality Technology Demonstration, Evaluation and Transfer Activities, Annual Report, USAEC, 2000
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, Fourth Edition, October 1995 Federal Publications on Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation, Fourth Edition, October 1995 FRTR Remediation Technologies Screening Matrix and Reference Guide, Version III, November 1997
EPA	The Superfund Innovative Technology Evaluation (SITE) Program: Technology Profiles, Tenth Edition, 1999
DOE	Technology Catalogue, Second Edition, April 1995
USAF	Remedial Technology Design, Performance, and Cost Study, July 1992
California Military Environmental Coordination Committee	Treatment Technologies Applications Matrix for Base Closure Activities, Spring 1996
EPA/U.S. Navy	EPA/Navy CERCLA Remedial Action Technology Guide, November 1993