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Abstracts of Remediation Case Studies

Volume 4

Federal
Remediation
Technologies
Roundtable
<www.frtr.gov>

Prepared by the

Member Agencies of the
Federal Remediation Technologies Roundtable

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Federal Remediation Technologies Roundtable

Environmental Protection Agency
Department of Defense
    U.S. Air Force
    U.S. Army
    U.S. Navy
Department of Energy
Department of Interior
National Aeronautics and Space Administration
Tennessee Valley Authority
Coast Guard

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NOTICE

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FOREWORD

This report is a collection of abstracts summarizing 78 case studies of site remediation applications prepared by federal agencies. The case studies, collected under the auspices of the Federal Remediation Technologies Roundtable, were undertaken to document the results and lessons learned from technology applications. They will help establish benchmark data on cost and performance which should lead to greater confidence in the selection and use of cleanup technologies.

The Roundtable was created to exchange information on site remediation technologies, and to consider cooperative efforts that could lead to a greater application of innovative technologies. Roundtable member agencies, including the U.S. Environmental Protection Agency, U.S. Department of Defense, and U.S. Department of Energy, expect to complete many site remediation projects in the near future. These agencies recognize the importance of documenting the results of these efforts, and the benefits to be realized from greater coordination.

The case study reports and abstracts are organized by technology in a multi-volume set listed below. The 78 new case studies are available on a CD-ROM, and cover a variety of in situ and ex situ technologies. Remediation Case Studies, Volumes 1-13, and Abstracts, Volumes 1-3, were published previously, and contain 140 projects, and are also available on the CD-ROM. Abstracts, Volume 4, covers a wide variety of technologies, including full-scale remediations and large-scale field demonstrations of soil and groundwater treatment technologies. In the future, the set will grow as agencies prepare additional case studies.

2000 Series

Published on CD-ROM, FRTR Cost and Performance Case Studies and Related Information, EPA-542-C-00-001; June 2000

1998 Series

Volume 7:	Ex Situ Soil Treatment Technologies (Bioremediation, Solvent Extraction, Thermal Desorption), EPA-542-R-98-011; September 1998
Volume 8:	In Situ Soil Treatment Technologies (Soil Vapor Extraction, Thermal Processes), EPA-542-R-98-012; September 1998
Volume 9:	Groundwater Pump and Treat (Chlorinated Solvents), EPA-542-R-98-013; September 1998
Volume 10:	Groundwater Pump and Treat (Nonchlorinated Contaminants), EPA-542-R-98-014; September 1998
Volume 11:	Innovative Groundwater Treatment Technologies, EPA-542-R-98-015; September 1998
Volume 12:	On-Site Incineration, EPA-542-R-98-016; September 1998
Volume 13:	Debris and Surface Cleaning Technologies, and Other Miscellaneous Technologies, EPA-542-R-98-017; September 1998

1997 Series

Volume 5: Bioremediation and Vitrification, EPA-542-R-97-008; July 1997; PB97-177554

Volume 6: Soil Vapor Extraction and Other In Situ Technologies, EPA-542-R-97-009; July 1997; PB97-177562

1995 Series

Volume 1: Bioremediation, EPA-542-R-95-002; March 1995; PB95-182911

Volume 2: Groundwater Treatment, EPA-542-R-95-003; March 1995; PB95-182929

Volume 3: Soil Vapor Extraction, EPA-542-R-95-004; March 1995; PB95-182937

Volume 4: Thermal Desorption, Soil Washing, and In Situ Vitrification, EPA-542-R-95-005; March 1995; PB95-182945

Abstracts

Volume 1: EPA-542-R-95-001; March 1995; PB95-201711

Volume 2: EPA-542-R-97-010; July 1997; PB97-177570

Volume 3: EPA-542-R-98-010; September 1998

Volume 4: EPA-542-R-00-006; June 2000

Accessing Case Studies

The case studies and case study abstracts also are available on the Internet through the Federal Remediation Technologies Roundtable web site at: http://www.frtr.gov. The Roundtable web site provides links to individual agency web sites, and includes a search function. The search function allows users to complete a key word (pick list) search of all the case studies on the web site, and includes pick lists for media treated, contaminant types, and primary and supplemental technology types. The search function provides users with basic information about the case studies, and allows them to view or download abstracts and case studies that meet their requirements.

Users are encouraged to download abstracts and case studies from the Roundtable web site. Some of the case studies are also available on individual agency web sites, such as for the Department of Energy.

In addition, a limited number of hard copies are available free of charge by mail from NSCEP (allow 4-6 weeks for delivery), at the following address:

U.S. EPA/National Service Center for Environmental Publications (NSCEP)
P.O. Box 42419
Cincinnati, OH 45242
Phone: (513) 489-8190 or
(800) 490-9198
Fax: (513) 489-8695

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ABSTRACTS

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INTRODUCTION

Increasing the cost effectiveness of site remediation is a national priority. The selection and use of more cost-effective remedies requires better access to data on the performance and cost of technologies used in the field. To make data more widely available, member agencies of the Federal Remediation Technologies Roundtable (Roundtable) are working jointly to publish case studies of full-scale remediation and demonstration projects. Previously, the Roundtable published 13 volumes of case study reports. At this time, the Roundtable is publishing a CD-ROM containing 78 new case study reports, primarily focused on soil and groundwater cleanup.

The case studies were developed by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Defense (DoD), and the U.S. Department of Energy (DOE). They were prepared based on recommended terminology and procedures agreed to by the agencies. These procedures are summarized in the Guide to Documenting and Managing Cost and Performance Information for Remediation Projects (EPA 542-B-98-007; October 1998).

The case studies and abstracts present available cost and performance information for full-scale remediation efforts and several large-scale demonstration projects. They are meant to serve as primary reference sources, and contain information on site background and setting, contaminants and media treated, technology, cost and performance, and points of contact for the technology application. The studies contain varying levels of detail, reflecting the differences in the availability of data and information. Because full-scale cleanup efforts are not conducted primarily for the purpose of technology evaluation, data on technology cost and performance may be limited.

The case study abstracts in this volume describe a wide variety of ex situ and in situ soil treatment technologies for both soil and groundwater. Contaminants treated included chlorinated solvents; petroleum hydrocarbons and benzene, toluene, ethylbenzene, and xylenes; polycyclic aromatic hydrocarbons; pesticides and herbicides; explosives/propellants; metals; and radioactivity. Many of the applications described in the case study reports are ongoing and interim reports are provided documenting their current status.

Table 1 provides summary information about the technology used, contaminants and media treated, and project duration for the 78 technology applications in this volume. This table also provides highlights about each application. Table 2 summarizes cost data, including information on quantity of media treated and quantity of contaminant removed. In addition, Table 2 shows a calculated unit cost for some projects, and identifies key factors potentially affecting technology cost. (The column showing the calculated unit costs for treatment provides a dollar value per quantity of media treated and contaminant removed, as appropriate.) Cost data are shown as reported in the case studies and have not been adjusted for inflation to a common year basis. The costs should be assumed to be dollars for the time period that the project was in progress (shown on Table 1 as project duration).

While a summary of project costs is useful, it may be difficult to compare costs for different projects because of unique site-specific factors. However, by including a recommended reporting format, the Roundtable is working to standardize the reporting of costs to make data comparable across projects. In addition, the Roundtable is working to capture information in case study reports that identify and describe the primary factors that affect cost and performance of a given technology. Factors that may affect project costs include economies of scale, concentration levels in contaminated media, required cleanup levels, completion schedules, and matrix characteristics and operating conditions for the technology.

Table 1. Summary of Remediation Case Studies

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated**)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Explosives/Propellants	Metals	Radionuclides			
In Situ Soil Treatment									
Dover Air Force Base, Building 719, Delaware (Bioventing)	●						Soil (450,000 lbs)	May 1998 to July 1999	Field demonstration of in situ cometabolic bioventing to treat chlorinated solvents in soil
Multiple Air Force Test Sites, Multiple Locations (Bioventing)		●					Soil (200 to 270,000 yd^3 per site)	April 1992 to December 1995 (typical test about 1 year)	Major initiative to demonstrate the feasibility of bioventing for petroleum-contaminated soil at 145 AF sites
White Sands Missile Range, SWMU 143, New Mexico (Chemical Reduction/Oxidation)					●		Soil	April 1998 to June 1998	Demonstrate use of injection of H_2S for in situ reduction of hexavalent chromium
Active Power Substation, Confidential Location (Electrokinetics)							Soil	Summer 1998 (6 month pilot-scale study)	First field demonstration of electrokinetic remediation in the U. S. for arsenic-contaminated soil
Naval Air Weapons Station Point Mugu, Site 5, California (Electrokinetics)					●		Soil	March 1998 to June 1999	Field demonstration of electrokinetics for treatment of metals in a sandy soil
Sandia National Laboratories, Unlined Chromic Acid Pit, New Mexico (Electrokinetics)					●		Soil	May 1996 to November 1996	The first field demonstration of electrokinetics for removal of contaminant ions from arid soil
Former Mare Island Naval Shipyard, California (In Situ Thermal Treatment; In Situ Thermal Desorption)							Soil	September 1997 to December 1997	Field demonstration of in situ thermal desorption to treat PCBs in shallow and deep contaminated soils
Fort Richardson Poleline Road Disposal Area, OU B, Alaska (In Situ Thermal Treatment; Six Phase Heating)	●						Soil (3,910 yd^3 or 7,150 tons)	July 1997 to December 1997 (treatability Study)	Demonstration of SPSH applied to contamination in saturated soils.
Argonne National Laboratory - West, Waste Area Group 9, OU 9-04, Idaho (Phytoremediation)					●		Soil	May 1998 to October 1998	Bench-scale testing of phytoremediation to treat heavy metals in soil
Ensign-Bickford Company - OB/OD Area, Connecticut (Phytoremediation)					●		Soil	April 1998 to October 1998	Phytoremediation of lead in soil using both phytoextraction and phytostabilization
Twin Cities Army Ammunition Plant, Minnesota (Phytoremediation)					●		Soil	Spring/Summer 1998	Phytoremediation of heavy metals in soil in a northern climate

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated**)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Explosives/Propellants	Metals	Radionuclides			
Patrick Air Force Base, Active Base Exchange Service Station, Florida (Soil Vapor Extraction)		●					Soil vapors	January 1994 to February 1994	Demonstration of treatment of extracted vapors from an SVE system using biofiltration
Patrick Air Force Base, Active Base Exchange Service Station, Florida (Soil Vapor Extraction)		●					Soil vapors	October 1993 to January 1994	Demonstration of treatment of extracted vapors from an SVE system using an internal combustion engine
Vandenberg Air Force Base, Base Exchange Service Station, California (Soil Vapor Extraction)		●					Soil vapors	February 1994 to June 1994	Demonstration of treatment of extracted vapors from an SVE system using resin adsorption
Idaho National Engineering and Environmental Laboratory, Pit 2, Idaho (Soil venting, BERT^{TM})	●						Soil	December 1996 to January 1999	Demonstrate use of passive soil venting for remediation of VOC-contamination
Incineration									
Former Weldon Springs Ordnance Works, OU 1, Missouri (Incineration (on-site))				●			Soil (30,000 tons or 18,000 yd^3) Wooden pipeline	August 1998 to 1999	Use of on-site incineration for treatment of nitroaromatic-contaminated materials
Thermal Desorption									
Arlington Blending and Packaging Superfund Site, Tennessee (Thermal Desorption)			●		●		Soil (41,431 tons)	January 1996 to June 1996	Application of low temperature thermal desorption to treat pesticide-contaminated soil
Letterkenny Army Depot Superfund Site, K Areas, OU1, Pennsylvania (Thermal Desorption)	●				●		Soil (13,986 yd^3)	September 1993 to October 1994	Thermal desorption to treat VOC-contaminated soil, including soils with high oil and grease content
Longhorn Army Ammunition Plant, Burning Ground No. 3, Texas (Thermal Desorption)	●						Soil (32,293 yd^3 or 51,669 tons)	February 1997 to December 1997	Thermal desorption of soil with high concentrations of chlorinated solvents
Rocky Flats Environmental Technology Site, Trenches T-3 and T-4, Colorado (Thermal Desorption)	●					●	Soil and debris (3,796 yd^3)	June 1996 to August 1996	Application of thermal desorption to treat soils contaminated with VOCs and low levels of radiation

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated**)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Explosives/Propellants	Metals	Radionuclides			
Other Ex Situ Soil Treatment									
Joliet Army Ammunition Plant, Illinois (Bioremediation (ex situ) Slurry Phase)				●			Soil	July 1994 to August 1995	Use of bioslurry technology for treatment of explosives wastes
Fort Polk Range 5, Louisiana (Chemical Reduction/Oxidation)					●		Soil (1,098 tons)	August 1996 to December 1996	Demonstration of physical separation and acid leaching to treat metals in soil
Los Alamos National Laboratory, Technical Area 33, New Mexico (Physical Separation; Segmented Gate System)						●	Soil and debris (2,526 yd^3)	April 1999 to May 1999	Use of a gate system to reduce soil volume requiring off-site disposal
Pantex Plant, Firing Site 5, Texas (Physical Separation; Segmented Gate System)						●	Soil and debris (294 yd^3)	March 1998 to May 1998	Use of a gate system to reduce soil volume requiring off-site disposal
Sandia National Laboratories, ER Site 16, New Mexico (Physical Separation; Segmented Gate System)						●	Soil (661.8 yd^3)	February 1998 to March 1998	Use of a gate system to reduce soil volume requiring off-site disposal
Sandia National Laboratories, ER Site 228A, New Mexico (Physical Separation; Segmented Gate System)						●	Soil (1,352 yd^3)	July 1998 to November 1998	Use of a gate system to reduce soil volume requiring off-site disposal
Tonapah Test Range, Clean Slate 2, Nevada (Physical Separation; Segmented Gate System)						●	Soil and debris (333 yd^3)	May 1998 to June 1998	Use of a gate system to reduce soil volume requiring off-site disposal
RMI Titanium Company Extrusion Plant, Ohio (Solvent Extraction)					●	●	Soil (64 ton; 38 batches)	January 1997 to February 1997	Demonstration of chemical leaching process for treatment of uranium-contaminated soil
Oak Ridge National Laboratory, Tennessee (Vitrification)					●	●	Sludge (16,000 lbs)	October 1997	Demonstration of a transportable vitrification system to treat low-level mixed waste sludges
Pump and Treat									
Fort Lewis Logistics Center, Washington (Pump and Treat)	●						Groundwater (2.147 million gallons)	August 1995 to ongoing	Containment of lateral migration of contaminants

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated**)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Explosives/Propellants	Metals	Radionuclides			
In Situ Groundwater Treatment									
Abandoned Manufacturing Facility - Emeryville, California (Bioremediation (in situ) Groundwater)	●				●		Groundwater	Ongoing, data from April 1997 to October 1998	Bioremediation of a site contaminated with both chlorinated solvents and hexavalent chromium
Avco Lycoming Superfund Site, Pennsylvania (Bioremediation (in situ) Groundwater)	●				●		Groundwater	Ongoing, data through July 1998	One of the first applications of molasses injection technology on a full scale at a Superfund site
Dover Air Force Base, Area 6, Delaware (Bioremediation (in situ) Groundwater)	●						Groundwater	Testing Phase: September 1996 to June 1999	First successful bioaugmentation project using live bacteria from another site to treat TCE using reductive dechlorination
Edwards Air Force Base, California (Bioremediation (in situ) Groundwater)	●						Groundwater (12,132 m^3 pumped)	February 1996 to April 1997	Field demonstration using groundwater recirculation wells to remediate TCE in a two-aquifer system
Hanford 200 West Area, Washington (Bioremediation (in situ) Groundwater)	●						Groundwater	January 1995 to March 1996	In situ bioremediation of chlorinated solvents and nitrate
Moffett Field Superfund Site, California (Bioremediation (in situ) Groundwater)	●						Groundwater	September 1986 to November 1988	One of the earliest field demonstrations of aerobic in situ bioremediation
Naval Weapons Station Seal Beach, California (Bioremediation (in situ) Groundwater)		●					Groundwater (in situ), Soil (in situ), LNAPL	September 1997 to October 1998	Demonstrate anaerobic bioremediation for treating fuel hydrocarbons
Watertown Site, Massachusetts (Bioremediation (in situ) Groundwater)	●						Groundwater	Ongoing, data from November 1996 to October 1997	Combined anaerobic/aerobic system for treatment of chlorinated solvents
Savannah River Site, South Carolina (Bioremediation (in situ) Groundwater)	●						Groundwater and sediment	February 1992 to April 1993	Demonstration using horizontal wells and methane injection
Texas Gulf Coast Site, Texas (Bioremediation (in situ) Groundwater)	●						Groundwater	Ongoing, data from June 1995 to December 1998	Groundwater recirculation system using trenches for extraction and injection
Hanford Site, 100-H and 100-D Areas, Washington (Chemical Reduction/Oxidation)					●		Groundwater	September 1995 to September 1998	Demonstrate in situ redox manipulation for treatment of hexavalent chromium

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated**)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Explosives/Propellants	Metals	Radionuclides			
Portsmouth Gaseous Diffusion Plant, X-701B Facility, Ohio (Chemical Reduction/Oxidation)	●						Groundwater (in situ)	Spring 1997 (operated for one month)	Demonstrate in situ chemical oxidation for treating chlorinated solvents
Milan Army Ammunition Plant, Tennessee (Constructed Wetlands)				●			Groundwater	June 1996 to July 1998	Use of constructed wetlands for treatment of explosives-contaminated groundwater
328 Site, California (Dual-Phase Extraction)	●						Soil and Groundwater	November 1996 to May 1999	Use of DPE with pneumatic fracturing for VOCs in silty clay soils and shallow groundwater
Defense Supply Center, Acid Neutralization Pit, Virginia (Dual-Phase Extraction)	●						Soil, Groundwater (17 million gallons)	July 1997 to July 1998	Use of DPE to treat soil and groundwater contaminated with chlorinated solvents
Tinkham's Garage Superfund Site, New Hampshire (Dual-Phase Extraction)	●						Soil (9,000 yd^3) Groundwater	November 1994 to September 1995	Use of DVE to treat soil and groundwater contaminated with chlorinated solvents
Oak Ridge National Laboratory, Tennessee (Frozen Soil Barrier)						●	Soil, Sediment, Groundwater	September 1996 to September 1998	Demonstrate frozen soil barrier for containment of contaminated surface impoundment
Portsmouth Gaseous Diffusion Plant, X-701B Facility, Ohio (In Situ Oxidation)	●						Groundwater (in situ)	1988 to 1993	Demonstrate use of horizontal wells to treat groundwater at multiple sites and locations
Naval Air Station Pensacola, OU 10, Florida (In Situ Oxidation; Fenton's Reagent)	●						Groundwater	November 1998 to May 1999	Field demonstration of in situ chemical oxidation using Fenton's reagent to treat chlorinated solvents
Naval Submarine Base Kings Bay, Georgia (In Situ Oxidation; Fenton's Reagent)	●						Groundwater (78,989 gallons)	November 1998 to August 1999	Use of Fenton’s Reagent to remediate chlorinated solvents in groundwater
Confidential Manufacturing Facility, Illinois (In Situ Thermal Treatment; Six Phase Heating)	●						Soil and groundwater (34,600 yd^3)	June 1998 to April 1999	Use of SPH to remediate chlorinated solvents in soil and groundwater
Visalia Superfund Site, California (In Situ Thermal Treatment; Dynamic Underground Stripping)							Groundwater	June 1997 to mid-1999	Use of HPO/DUS for treatment of large quantity of creosote in groundwater
Fort Devens, AOCs 43G and 43J, Massachusetts (Monitored Natural Attenuation)		●					Groundwater	March 1997 to June 1999	Intrinsic remediation for a site contaminated with BTEX

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated**)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Explosives/Propellants	Metals	Radionuclides			
Keesler Air Force Base Service Station, AOC-A (ST-06), Mississippi (Monitored Natural Attenuation)		●			●		Soil, groundwater, and soil gas	September 1997 to April 1999	Monitored natural attenuation for a gasoline contaminated site
Kelly Air Force Base, Former Building 2093 Gas Station, Texas (Monitored Natural Attenuation)		●					Soil, groundwater, and soil gas	July 1997 to July 1998	Monitored natural attenuation for a gasoline-contaminated site
Fry Canyon, Utah (Permeable Reactive Barrier)					●	●	Groundwater (33,000 ft^3 or 200,000 gallons)	Ongoing, data from September 1997 to September 1998	Demonstration of three types of PRBs to treat uranium-contaminated groundwater
Moffett Field Superfund Site, California (Permeable Reactive Barrier)	●						Groundwater	April 1996 to December 1997	Demonstration of PRB to remediate groundwater contaminated with chlorinated solvents
Tacony Warehouse, Pennsylvania (Permeable Reactive Barrier; Pump and Treat)	●						Groundwater (393,165 gallons during the first year)	May 1998 through 2001 (projected)	Use of an extraction well surrounded by permeable reactive media at site contaminated with chlorinated solvents.
Debris/Solid Media Treatment									
Lawrence Livermore National Laboratory, California (Chemical Reduction/Oxidation; Direct Chemical Oxidation)	●			●			Waste streams from LLNL operations	Not identified	Pilot-scale demonstration of the DCO process to treat a variety of organic aqueous waste streams
Savannah River Site, South Carolina (Chemical Reduction/Oxidation)						●	Organic wastes	1996 to 1997	Demonstrate acid digestion of organic wastes as an alternative to incineration
Argonne National Laboratory - East, Illinois (Physical Separation)						●	Debris (concrete)	August 1997 to September, 1997	Demonstration of a remotely-controlled concrete demolition system to remove radioactively contaminated concrete
Argonne National Laboratory - East, Illinois (Physical Separation)						●	Debris (concrete floor)	Not identified	Demonstration of a remotely-operated scabbler to decontaminate radioactive concrete flooring
Fernald Site, Ohio (Physical Separation)						●	Debris	August 1996 to September 1996	Demonstration of soft blast media to clean surfaces contaminated with uranium

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants* Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Explosives/Propellants	Metals	Radionuclides	Media (Quantity Treated**)	Project Duration	Highlights
Hanford Site, Washington (Physical Separation)						●	Debris (concrete) (54 ft^2)	November 1997	Demonstration of a light weight hand-held grinder to decontaminate radioactive concrete surfaces
Hanford Site, Washington (Physical Separation)						●	Debris (concrete)	November 1997	Demonstration of a concrete shaver to decontaminate radioactive concrete surfaces
Hanford Site, Washington (Physical Separation)						●	Debris (contaminated concrete walls and floors) (4.6m^2)	January 1998	First demonstration of the hand-held concrete spaller on contaminated surfaces
Argonne National Laboratory - East, Illinois (Solidification/Stabilization)					●		Salt-containing waste streams	Not identified	Demonstration of phosphate-bonded ceramics to stabilize a variety of high salt-containing wastes
Clemson University, South Carolina (Solidification/Stabilization)					●		Incinerator fly ash	1995	Treatability study of stabilization of mixed waste fly ash using a sintering process
Hanford Site, Washington (Solidification/Stabilization)					●	●	Process waste streams	Not identified	Treatability study of various polyester resins to stabilize high salt-containing mixed waste
Idaho National Engineering and Environmental Laboratory, Idaho (Solidification/Stabilization)						●	Soil and debris	Summer 1994 to Summer 1996	Field demonstration of innovative jet grouting and retrieval techniques that are applicable to TRU wastes
Idaho National Engineering and Environmental Laboratory, Idaho (Solidification/Stabilization)					●		Process waste streams	1997 to 1998	Demonstration of polysiloxane to encapsulate high-salt content wastes
Idaho National Engineering and Environmental Laboratory, Idaho (Solidification/Stabilization)					●		Liquid mercury (75 kg)	1998	Demonstrate amalgamation of elemental mercury
Los Alamos National Laboratory, New Mexico (Solidification/Stabilization)					●		Liquid mercury (132 kg)	1998	Demonstrate amalgamation of elemental mercury
Los Alamos National Laboratory, New Mexico (Solidification/Stabilization)	●				●	●	Sludge (1,253 lbs) Laboratory Wastes	September 1997 to September 1998	Demonstrate stabilization of low level mercury in radioactive wastes

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated**)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Explosives/Propellants	Metals	Radionuclides			
Pacific Northwest National Laboratory, Washington (Solidification/Stabilization)					●		Salt waste surrogates	Not identified	Laboratory testing of the sol gel process to stabilize high salt content waste
Portsmouth Gaseous Diffusion Plant, Ohio (Solidification/Stabilization)					●	●	Ion exchange resin (160 kg)	1998	Demonstrate stabilization of low level mercury in radioactive wastes
Idaho National Engineering and Environmental Laboratory, Idaho (Vitrification)					●	●	Wastes - including slag, plutonium-238 waste, neutron generators	1997 to 1998	Demonstrate DC arc plasma furnace to treat a variety of wastes from DOE facilities
STAR Center, Idaho (Vitrification)					●	●	Fly ash, soil, sludges, debris	1993 to 1997	Demonstration of a plasma hearth furnace to treat metals and radionuclides in a variety of waste types

* Principal contaminants are one or more specific constituents within the groups shown that were identified during site investigations.

Table 2. Remediation Case Studies: Summary of Cost Data

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs***
In Situ Soil Treatment					
Dover Air Force Base, Building 719, Delaware (Bioventing)	Not provided	450,000 lbs	Not provided	Not provided	Not provided
Multiple Air Force Test Sites, Multiple Locations (Bioventing)	P: $92,300	200 to 270,000 cubic yards per site	Not provided	P: $10 to $60 per cubic yard	Volume of soil treated, with lower costs for sites with >10,000 yds[3]
White Sands Missile Range, SWMU 143, New Mexico (Chemical Reduction/Oxidation)	P: $798,163	Not provided	Not provided	P: $43 to $100 per cubic yard	Size of the waste site
Active Power Substation, Confidential Location (Electrokinetics)	Not provided	Not provided	Not provided	Not provided	Not provided
Naval Air Weapons Station Point Mugu, Site 5, California (Electrokinetics)	Not provided	Not provided	Not provided	Not provided	Not provided
Sandia National Laboratories, Unlined Chromic Acid Pit, New Mexico (Electrokinetics)	Not provided	Not provided	Not provided	Not provided	Not provided
Former Mare Island Naval Shipyard, California (In Situ Thermal Treatment; In Situ Thermal Desorption)	Not provided	Not provided	Not provided	$100 to $250 per ton (vendor estimate)	Not provided
Fort Richardson Poleline Road Disposal Area, OU B, Alaska (In Situ Thermal Treatment; Six Phase Heating)	$967,822	3,910 cubic yards	Not provided	$189 to $288 per cubic yard, $726 to $2,552 per lb of contaminant removed	Availability and cost for power
Argonne National Laboratory - West, Waste Area Group 9, OU 9-04, Idaho (Phytoremediation)	P: $2,247,000	Not provided	Not provided	Not provided	Amount of time needed to meet goals and size of area treated
Ensign-Bickford Company - OB/OD Area, Connecticut (Phytoremediation)	Not provided	Not provided	Not provided	Not provided	Not provided
Twin Cities Army Ammunition Plant, Minnesota (Phytoremediation)	Not provided	Not provided	Not provided	$30.34 per cubic yard of soil per year ($153 per cubic yard over the life of the project)	Amount of time needed to meet goals and size of area treated
Patrick Air Force Base, Active Base Exchange Service Station, Florida (Soil Vapor Extraction - Biofiltration)	Not provided	Not provided	Not provided	$18.66 to $38.06 per kg (costs estimates were provided by other vendors)	Contaminant concentration and flow rate

Table 2. Remediation Case Studies: Summary of Cost Data (continued)

Site Name, State (Technology)	Technology Cost ($)^{1,2}	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment ^{1,2}	Key Factors Potentially Affecting Technology Costs***
Patrick Air Force Base, Active Base Exchange Service Station, Florida (Soil Vapor Extraction - Thermal Destruction)	Not provided	Not provided	Not provided	Operating costs of $0.83 to $15.40 per kg TVH destroyed, $97 to $550 per kg of BTEX destroyed	Contaminant concentration and supplemental fuel requirement
Vandenberg Air Force Base, Base Exchange Service Station, California (Soil Vapor Extraction - Resin Adsorption)	DEMO: $36,634	Not provided	570 gals of hydrocarbons	DEMO: $23 per kg of hydrocarbon removed	Contaminant concentration and flow rate
Idaho National Engineering and Environmental Laboratory, Pit 2, Idaho (Soil venting BERT^{TM})	P: $67,860	Not provided	Chlorinated solvents ranged from 0.25 to 2.9 gms/day	P: $100 per cubic yard	Size of contaminated area and length of operation
Incineration					
Former Weldon Springs Ordnance Works, OU 1, Missouri (Incineration (on-site))	$13,665,997	30,000 tons (18,000 cubic yards) 85,230 feet of pipeline	Not provided	Not provided	Types and properties of materials treated (such as moisture content, BTU value)
Thermal Desorption					
Arlington Blending and Packaging Superfund Site, Tennessee (Thermal Desorption)	C: $4,293,893 O: $62,351	41,431 tons	Not provided	$105 per ton	Types and properties of materials treated such as moisture content and types of contaminants (pesticides)
Letterkenny Army Depot Superfund Site, K Areas, OU1, Pennsylvania (Thermal Desorption)	$4,647,632	13,986 cubic yards	Not provided	$220 per cubic yard	Types and properties of materials treated such as moisture content and types of contaminants (high oil and grease content)
Longhorn Army Ammunition Plant, Burning Ground No. 3, Texas (Thermal Desorption)	$4,886,978	32,293 cubic yards (51,669 tons)	Not provided	$151 per cubic yard	Types and properties of materials treated such as moisture content and types of contaminants (solvents)
Rocky Flats Environmental Technology Site, Trenches T-3 and T-4, Colorado (Thermal Desorption)	$1,934,203	3,796 cubic yards	Not provided	$350 per cubic yard	Use of radiological engineering controls

Table 2. Remediation Case Studies: Summary of Cost Data (continued)

Site Name, State (Technology)	Technology Cost ($)^{1,2}	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment ^{1,2}	Key Factors Potentially Affecting Technology Costs***
Other Ex Situ Soil Treatment					
Joliet Army Ammunition Plant, Illinois (Bioremediation (ex situ) Slurry Phase)	Not provided	Not provided	Not provided	P: $290 to $350 per cubic yard	Use of additives and frequency of replacement
Fort Polk Range 5, Louisiana (Physical Separation and Acid Leaching)	DEMO: $1,169,000 P: $1,700,000	DEMO: 835 tons PC: 10,000 tons	Not provided	DEMO: $1,400 per ton P: $170 per ton	Volume of waste treated and level of treatment required to regenerate leachate
Los Alamos National Laboratory, Technical Area 33, New Mexico (Physical Separation; Segmented Gate System)	$275,745	2,526 cubic yards	Not provided	$109 per cubic yard	Quantity of material processed
Pantex Plant, Firing Site 5, Texas (Physical Separation; Segmented Gate System)	$203,887	294 cubic yards	Not provided	$111 per cubic yard	Quantity of material processed
Sandia National Laboratories, ER Site 16, New Mexico (Physical Separation; Segmented Gate System)	$164,109	661.8 cubic yards	Not provided	$236 per cubic yard	Quantity of material processed
Sandia National Laboratories, ER Site 228A, New Mexico (Physical Separation; Segmented Gate System)	$220,040	1,352 cubic yards	Not provided	$154 per cubic yard	Quantity of material processed
Tonapah Test Range, Clean Slate 2, Nevada (Physical Separation; Segmented Gate System)	$138,126	333 cubic yards	Not provided	Not provided	Quantity of material processed
RMI Titanium Company Extrusion Plant, Ohio (Solvent Extraction)	Pilot: $638,670	64 tons (38 batches)	Not provided	P: $250 to $350 per ton of soil	Contaminant concentrations and amount of heating required for solvent
Oak Ridge National Laboratory, Tennessee (Vitrification)	C: $5,000,000 AO: $10 to $44 per kg of waste	16,000 lbs of pond and neutralization sludge	Not provided	Not provided	Size of area treated; energy requirements; and level of emission controls required

Table 2. Remediation Case Studies: Summary of Cost Data (continued)

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs***
Pump and Treat					
Fort Lewis Logistics Center, Washington (Pump and Treat)	$5,208,000	2.147 million gallons (through 8/98)	2,772 lbs of TCE (through 9/97)	Not provided	Length of system operation; presence of DNAPL
In Situ Groundwater Treatment					
Abandoned Manufacturing Facility - Emeryville, California (Bioremediation (in situ) Groundwater)	$400,000	Not provided	Not provided	Not provided	Size of area treated; amount and frequency of molasses injections required
Avco Lycoming Superfund Site, Pennsylvania (Bioremediation (in situ) Groundwater)	C: $220,000 AO: $50,000	Not provided	Not provided	Not provided	Size of area treated; amount and frequency of molasses injections required
Dover Air Force Base, Area 6, Delaware (Bioremediation (in situ) Groundwater)	C: $285,563 O: $522,620 (for 15 months)	Not provided	Not provided	Not provided	Size of area treated; amount and type of additives
Edwards Air Force Base, California (Bioremediation (in situ) Groundwater)	C: $323,452 O: $14,354	Not provided	12,132 cubic meters	Not provided	Size of area treated; two contaminated aquifers
Hanford 200 West Area, Washington (Bioremediation (in situ) Groundwater)	Not provided	Not provided	Not provided	P: $5.80 per cubic meter	Plume size - cost effective for small plumes (100 m diameter)
Moffett Field Superfund Site, California (Bioremediation (in situ) Groundwater)	Not provided	Not provided	Not provided	Not provided	Not provided
Naval Weapons Station Seal Beach, California (Bioremediation (in situ) Groundwater)	DEMO: $875,000 P: $1,085,000	Not provided	Not provided	P: $4,340 per gallon of fuel	Size of area treated; for demo, analytical costs
Watertown Site, Massachusetts (Bioremediation (in situ) Groundwater)	DEMO: $150,000	Not provided	Not provided	Not provided	Not provided
Savannah River Site, South Carolina (Bioremediation (in situ) Groundwater)	PC: $452,407 PAO: $236,465	Not provided	17,000 lbs VOCs	Not provided	Size of area treated; DNAPL present
Texas Gulf Coast Site, Texas (Bioremediation (in situ) Groundwater)	C: $600,000 AO: $100,000	Not provided	Not provided	Not provided	Size of area treated; use of methanol as additive
Hanford Site, 100-H and 100-D Areas, Washington (Chemical Reduction/Oxidation)	Not provided	Not provided	Not provided	Not provided	Not provided

Table 2. Remediation Case Studies: Summary of Cost Data (continued)

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs***
Portsmouth Gaseous Diffusion Plant, X-701B Facility, Ohio (Chemical Reduction/Oxidation)	DEMO: $562,000 P: $516,360	Not provided	Not provided	P: $64 per cubic yard	Size of area treated; DNAPL present
Milan Army Ammunition Plant, Tennessee (Constructed Wetlands)	P: $3,466,000	Not provided	Not provided	P: $1.78 per 1,000 gallons of groundwater	Type of system used (gravel vs. lagoon-based), size of area treated, and climate
328 Site, California (Dual-Phase Extraction)	C: $300,000 O: $550,000	Not provided	1,220 lbs VOCs	$53 per cubic yard (based on treatment of 16,000 cubic yards)	Use of pneumatic fracturing; contamination in two aquifer zones
Defense Supply Center, Acid Neutralization Pit, Virginia (Dual-Phase Extraction)	Treat: $538,490	17 million gallons of groundwater	145 lbs VOCs	Treat: $0.03 per gallon	Volume of groundwater treated; contamination confined to upper aquifer
Tinkham's Garage Superfund Site, New Hampshire (Dual-Phase Extraction)	$1,500,000	9,000 cubic yards	Not provided	$170 per cubic yard	Size of area treated; contamination in two aquifer zones
Oak Ridge National Laboratory, Tennessee (Frozen Soil Barrier)	DEMO: $1,809,000	Not provided	Not provided	Not provided	Complex hydrogeology due to presence of fractured bedrock
Savannah River Site, Aiken, South Carolina (Horizontal Wells)	Not provided	Not provided	Not provided	Not provided	Not provided
Naval Air Station Pensacola, OU 10, Florida (In Situ Oxidation; Fenton's Reagent)	DEMO C: $97,018 O: $81,320	Not provided	Not provided	Not provided	Volume of reagent injected and frequency of injections
Naval Submarine Base Kings Bay, Georgia (In Situ Oxidation; Fenton's Reagent)	Phase 1: $223,000	Phase 1: 78,989 gallons	Not provided	Not provided	Volume of reagent injected and frequency of injections
Confidential Manufacturing Facility, Illinois (In Situ Thermal Treatment; Six Phase Heating)	Not provided	Not provided	Not provided	$32 per cubic yard	Size of area treated; power requirements
Visalia Superfund Site, California (In Situ Thermal Treatment; Dynamic Underground Stripping)	Not provided	Not provided	141,000 gal of creosote	P: $39 per cubic yard	Groundwater extraction capacity and plume size
Fort Devens, AOCs 43G and 43J, Massachusetts (Monitored Natural Attenuation)	$671,642 PAO: $50,000	Not provided	Not provided	Not provided	Length of remediation; monitoring requirements

Table 2. Remediation Case Studies: Summary of Cost Data (continued)

Site Name, State (Technology)	Technology Cost (\$)^{1,2}	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment ^{1,2}	Key Factors Potentially Affecting Technology Costs***
Keesler Air Force Base Service Station, AOC-A (ST-06), Mississippi (Monitored Natural Attenuation)	PO: \$15,000 per event	Not provided	Not provided	Not provided	Length of remediation; monitoring requirements
Kelly Air Force Base, Former Building 2093 Gas Station, Texas (Monitored Natural Attenuation)	Not provided	Not provided	Not provided	Not provided	Not provided
Fry Canyon, Utah (Permeable Reactive Barrier)	DEMO C: \$674,000 PAO: \$55,000 to \$60,000	33,000 cubic feet (200,000 gallons through 9/98)	Not provided	Not provided	Type of reactive media; size of PRB
Moffett Field Superfund Site, California (Permeable Reactive Barrier)	PC: \$4,910,942 PAO: \$72,278	Not provided	Not provided	Not provided	Size of PRB and type of reactive material; projected costs assume PRB constructed in two sections
Tacony Warehouse, Pennsylvania (Permeable Reactive Barrier; Pump and Treat)	\$607,336 C: \$416,777 AO: \$16,880 Other: \$132,417	393,165 gallons during the first year	Not provided	Not provided	Size of PRB and type of reactive material
Debris/Solid Media Treatment					
Lawrence Livermore National Laboratory, California (Chemical Reduction/Oxidation)	Not provided	Not provided	Not provided	P: \$9.88 per kg of carbon in the waste if oxidant recycled; \$79 per kg of carbon if not recycled	Amount of carbon in waste stream; whether oxidant is recycled
Savannah River Site, South Carolina (Chemical Reduction/Oxidation)	P: \$2,000,000 to \$8,000,000	Not provided	Not provided	Not provided	Physical and chemical characteristics of waste stream; volume treated
Argonne National Laboratory - East, Argonne, Illinois (Concrete Scabbling)	C: \$165,000 O: \$1,995/day	Not provided	Not provided	Not provided	Area and depth of concrete surface treated; extent of particulate controls used
Fernald Site, Fernald, Ohio (Soft Media Blasting)	Not provided	Not provided	Not provided	DEMO: \$4.60 per square foot	Grade of media used; size and depth of concrete surface treated; noise protection used
Hanford Site, Hanford, Washington (Concrete Grinder)	C: \$854 (purchase); \$75/week (rental)	54 square feet	Not provided	Not provided	Size and depth of concrete surface treated

Table 2. Remediation Case Studies: Summary of Cost Data (continued)

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs***
Hanford Site, Washington (Concrete Shaver)	C: $17,861	Not provided	Not provided	$1.32 per square foot	Size and depth of concrete surface treated
Hanford Site, Washington (Concrete Spaller)	Not provided	4.6 square meters	Not provided	$128 per square meter	Size and depth of concrete surface treated
Argonne National Laboratory - East, Illinois (Phosphate Bonded Ceramic Stabilization)	PC: $2,000,000 PO: $6,510 per cubic meter of waste	Not provided	Not provided	Not provided	Salt loading in waste; types and concentrations of heavy metals
Clemson University, Clemson, South Carolina (Stabilization Using Clemson's Sintering Process)	Not provided	Not provided	Not provided	Not provided	Not provided
Hanford Site, Hanford, Washington (Polyester Resin Encapsulation)	PC: $2,000,000 PO: $5,940 per cubic meter of waste	Not provided	Not provided	Not provided	Salt loading in waste; types and concentrations of heavy metals
Idaho National Engineering and Environmental Laboratory, Idaho (Innovative Grouting and Retrieval)	P: $19,000,000 (1-acre); $64,000,000(4-acre)	Not provided	Not provided	Not provided	Size of area treated; physical and chemical characteristics of waste
Idaho National Engineering and Environmental Laboratory, Idaho (Polysiloxane Stabilization)	Not provided	Not provided	Not provided	$8 per pound ($573 per cubic foot) of salt waste	Salt loading in waste; types and concentrations of heavy metals
Idaho National Engineering and Environmental Laboratory, Idaho (Amalgamation of Mercury using the NFS De Hg^{SM} Process)	Not provided	75 kg of mercury	Not provided	P: $300 per kg (based on treating more than 1,500 kg)	Quantity of waste treated (costs prohibitive for small quantities)
Los Alamos National Laboratory, New Mexico (Amalgamation of Mercury using the ADA Process)	Not provided	132 kg of mercury	Not provided	P: $300 per kg (based on treating more than 1,500 kg)	Quantity of waste treated (costs prohibitive for small quantities)
Los Alamos National Laboratory, New Mexico (Solidification/Stabilization - GTS Duratek Process)	Not provided	Not provided	1,253 lbs of sludge, 3 containers of laboratory wastes	Not provided	Not provided
Pacific Northwest National Laboratory, Washington (Solidification/Stabilization - Sol Gel Process)	P: $600,000 to $1,000,000	Not provided	Not provided	Not provided	Salt loading in waste; types and concentrations of heavy metals

Table 2. Remediation Case Studies: Summary of Cost Data (continued)

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs***
Portsmouth Gaseous Diffusion Plant, Ohio (Solidification/Stabilization)	PC: 30,000 PO: $95 per hour	160 kg of resin	Not provided	$1.73 per kg	Types and concentrations of heavy metals
Idaho National Engineering and Environmental Laboratory, Idaho (Graphite Elctrode DC ARC Furnace)	PC: $50 to $80 million PO: $12 to $18 million (startup); $48 to $62 million (for 5yrs)	Not provided	Not provided	P: $7,400 to $10,800 per cubic meter (based on 17,000 cubic meters)	Physical characteristics of waste (moisture content); cost of power
STAR Center, Idaho (Plasma Hearth Process)	PC: $50 to 86.2 million PO: $12 to $18 million (startup); $48 to 62 million (for 5 yrs)	Not provided	Not provided	P: $7,400 to $10,800 per cubic meter	Physical characteristics of waste (moisture content); cost of power

[1] Actual full-scale costs are reported unless otherwise noted.

[2] Cost abbreviation: AO = annual operation and maintenance (O&M) costs, C = capital costs, D = disposal costs, DEMO = demonstration costs, O = total O&M costs, P = projected costs, Pilot = pilot-scale costs.

IN SITU SOIL TREATMENT ABSTRACTS

Cometabolic Bioventing at Building 719, Dover Air Force Base, Dover Delaware

Site Name:
Dover Air Force Base, Building 719

Location:
Dover, Delaware

Period of Operation:
Propane acclimation period: December 1997 to April 1998
Bioventing operation: May 1998 to July 1999

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Field demonstration of in situ cometabolic bioventing to treat chlorinated solvents in soil

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents
- Maximum concentrations of chlorinated aliphatic hydrocarbons (CAHs) in soil found during site investigations were TCE (250 mg/kg); TCA (1,000 mg/kg); DCE (20 mg/kg)
- Estimated mass of CAH in test plot - 26 pounds; TCA made up approximately 70% of the total estimated mass of contaminants
- Soil in the area is sand with varying amounts of clay, silt and gravel. Soil permeability is $1.9x10^{-7}$ to $7.0x10^{-8}$ cm^2.

Waste Source:
Discharges to a drainage ditch and sanitary sewer; leaks from underground and above ground tanks

Contacts:

EPA Remedial Project Manager:
Darius Ostrauskas
Remedial Project Manager
U.S. EPA Region 3
1650 Arch Street (3HS50)
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EPA Contact for Demonstration:
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U.S. EPA (mail stop 420)
26 W. Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7607
Fax: (513) 569-7105
E-mail: sayles.gregory@epa.gov

Technology:
In Situ Bioremediation; Cometabolic Bioventing
- Test plot - approximately 30 ft long, 20 ft wide, and 10 ft deep with a volume of 4,500 ft^3 of soil
- Three injection wells, screened to a depth of 10 ft bgs
- A blower and a mass flow controller were used to inject a mixture of air and propane (300 ppm in air) through the three wells at a rate of 1 cfm
- 13 soil gas monitoring points to monitor soil gas conditions throughout the demonstration. Each soil gas monitoring point was equipped with two gas probes (one at a depth of 4-5 ft and one at a depth of 8-9 ft bgs); an additional 11 "temporary" soil gas monitoring points were used during initial air permeability testing, and during system operation, to monitor soil gas

Type/Quantity of Media Treated:
Soil/ 450,000 lbs, based on an assumed density of 100 lbs/ft^3

Regulatory Requirements/Cleanup Goals:
The objectives of the pilot test included evaluating in situ cometabolic bioventing to treat chlorinated solvents in soil and to collect data for potential full-scale application of the technology at the site

Results:
- After 14 months of operation, concentrations of TCE, TCA, and DCE were reduced in the soil in the test area
- Reductions included TCE from >10 mg/kg to <0.25 mg/kg; TCA from >100mg/kg to <0.5mg/kg; and DCE from >20mg/kg to <0.25mg/kg

Costs:
Not provided

Cometabolic Bioventing at Building 719, Dover Air Force Base, Dover Delaware

Description:
Dover Air Force Base (AFB), located in Dover, Delaware, is a 4,000 acre military installation that began operating in 1941. Building 719 is a jet engine inspection and maintenance shop where a variety of materials, including solvents and fuel, were used un base operations. Until the mid-1960s, wastes from the shop were discharged to a drainage ditch and sanitary sewer. During site investigations, leaking tanks were identified in the area to the northeast of the shop, and soil and groundwater at the site was found to be contaminated with chlorinated solvents. Dover AFB was listed on the National Priorities List in March 1989. As part of the interim ROD for the site, a pilot test of in situ cometabolic bioventing was conducted at Building 719 to evaluate the ability of the technology to remove CAHs. The test plot selected for the pilot study was an area contaminated with high concentrations of CAHs. Prior to the pilot test, laboratory tests were performed on soils from the test plot area to evaluate candidate substrates. Propane was selected because of its ability to stimulate cometabolic activity towards both TCA and TCE.

The bioventing system used for the pilot test included three injection wells, screened to a depth of 10 ft bgs, which was the lowest expected water table elevation. In addition, soil gas conditions were monitored throughout the demonstration using soil gas monitoring points. In situ cometabolic bioventing was successful in reducing CAH concentrations in test plot soils. After 14 months of operation, TCE and DCE were reduced to concentrations of less than 0.25 mg/kg, and TCA was reduced to concentrations of less than 0.5 mg/kg. According to the researchers for the pilot test, results of laboratory treatability testing identified propane as a useful cosubstrate for driving the cometabolism of TCE and TCA.

Bioventing at Multiple Air Force Test Sites

Site Name:
Multiple Air Force Test Sites (145 total; refer to case study for names and locations of each test site)

Location:
Multiple locations throughout U.S.

Period of Operation:
- Overall program: April 1992 to December 1995
- Each test: varied by site; typical operation about one year

Cleanup Authority:
Sites are being addressed under CERCLA, RCRA, and state underground storage tank programs

Purpose/Significance of Application:
Major initiative to demonstrate the feasibility of bioventing to remediate petroleum-contaminated soil at 145 Air Force sites

Cleanup Type:
Pilot scale

Contaminants:
Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX) and Total Petroleum Hydrocarbons (TPH)
- Data provided for average initial concentrations of BTEX and TPH in soil and soil gas (based on 328 samples from 100 test sites)
- Average BTEX constituent concentrations in soil (soil gas) - benzene - 106 mg/kg (88 ppmv); toluene - 250 mg/kg (13 ppmv); ethylbenzene - 276 mg/kg (64 ppmv); xylenes - 1,001 mg/kg (46 ppmv)
- Average TPH concentration in soil - 3,301 mg/kg; Total Volatile Hydrocarbons (TVH) in soil gas - 22,555 ppmv

Waste Source:
Leaks from underground storage tanks, including tanks used to store gasoline, JP-4, diesel fuel, heating oils, and waste oils

Contacts:

Air Force Contact:
Lt. Col. Ross N. Miller
U.S. Air Force Center for
Environmental Excellence
Brooks, AFB
Texas
Telephone: 210-536-4331

Technology:
In Situ Bioventing
- Specific configuration varied by site for number, depth of vent (air injection) wells, number of monitoring wells, and blower size and type
- Typical configuration included vent wells (1 to 9 per site; depths -7 to 233 feet below ground surface); vapor monitoring wells (1 to 6 per site); blower (1 to 5 horsepower; either rotary vane or regenerative)
- Horizontal vent wells used at five sites

Type/Quantity of Media Treated:
Soil
- Quantities treated at each test site ranged from 200 to more than 270,000 cubic yards; based on radius of influence of vent well(s) at each site
- Soil gas permeability - about 20% of the test sites contained greater than 50% silt and clay fractions; the radius of oxygen influence from a single vent well was equal to or greater than the contaminated area at about 50% of the test sites
- Soil pH - pH ranged from 5 to 9 at the majority of sites
- Soil moisture - ranged from 5% to 20% at the majority of sites
- Total Kjeldahl nitrogen - ranged from <50 to 200 mg/kg at the majority of sites
- Soil temperature - not measured at each site; soil temperatures between 0°C and 25°C observed at test sites

Regulatory Requirements/Cleanup Goals:
- The objectives of the bioventing initiative included documenting the ability of bioventing to remediate petroleum-contaminated soils in a variety of conditions, and obtaining a significant set of bioventing data
- No specific cleanup goals were identified for the test sites

Bioventing at Multiple Air Force Test Sites

Results:

Results from data collected after one year of bioventing (328 sampling locations at 100 sites):

- Average reduction in BTEX concentrations of 97% in soil and 85% in soil gas; average TPH concentrations reduced by 24% in soil; average TVH concentrations reduced by 90% in soil gas
- Biodegradation rates measured at the test sites - at start of test ranged from <300 mg/kg/yr to >6000 mg/kg/yr; average 1,200 mg/kg/yr
- Average biodegradation rate decreased to 700 mg/kg/yr, as a result of the decreasing bioavailability of hydrocarbons over time
- Bioventing was effective in a variety of climate conditions, ranging from 0°C in Alaska to 25°C in California; higher biodegradation rates were observed in warmer climates
- A combination of high moisture content and fine-grained soils made bioventing infeasible at only two of the 145 test sites

Costs:

- The average actual cost for design, installation, and 1-year of operation of pilot-scale bioventing at a single vent well site was $60,000
- The projected cost of full-scale bioventing generally ranges from $10 to $60 per cubic yard of soil treated
- At sites with more than 10,000 cubic yards of contaminated soil, costs are less than $10 per cubic yard; at sites with less than 500 cubic yards of contaminated soil, costs are greater than $60 per cubic yard
- Projected costs for a typical full-scale bioventing system (defined as an Air Force site with 5,000 cubic yards of soil contaminated with 3,000 mg/kg of JP-4 fuel; bioventing system consisting of four vent wells at a depth of 15 feet, operated for two years) - $92,300, including $27,000 for pilot testing and $27,500 for full-scale construction

Description:

In April 1992, the Air Force Center for Environmental Excellence (AFCEE), in cooperation with the Air Force Armstrong Laboratory and the U.S. Environmental Protection Agency, began an initiative to demonstrate the feasibility of using bioventing to remediate petroleum contaminated soils in a variety of climatic, soil, and contaminant conditions. Between April 1992 and December 1995, initial bioventing tests were conducted at 145 Air Force sites throughout the country.

The pilot-scale systems included vent (air injection) wells, monitoring wells, and blowers. The specific configuration varied by test site, and horizontal vent wells were used at five of the sites. Concentrations of BTEX and TPH were measured in soil and soil gas from over 300 sampling locations at 100 sites at the start of bioventing operations and after one year of operation. Results showed that bioventing was effective in reducing concentrations of BTEX and TPH in soil and soil gas in a variety of site conditions. Soil BTEX and TPH concentrations were reduced by 97% and 24%, respectively. Soil gas BTEX and TVH concentrations were reduced by 85% and 90%, respectively. According to the Air Force, the reductions in BTEX are sufficient to meet the most conservative EPA risk-based cleanup criteria for soils, and regulatory acceptance of this technology was obtained in 38 states and the 10 EPA regions. The pilot-scale systems have been converted to full-scale systems at about half of the test sites, saving the Air Force an estimated $5 to $10 million in design and construction costs.

In Situ Gaseous Reduction System Demonstrated at White Sands Missile Range, New Mexico

Site Name:
White Sands Missile Range, SWMU 143

Location:
NM

Period of Operation:
April - June 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstrate use of injection of H_2S for in situ reduction of hexavalent chromium

Cleanup Type:
Field demonstration

Contaminants:
Heavy metals
- Cr^{6+}

Waste Source:
Spills

Contacts:

Technical Contacts:
Ed Thornton
Pacific Northwest National Laboratory (PNNL)
(509) 373-0358

DOE Contacts:
Jim Hanson
DOE EM50
(509) 372-4503

James A. Wright
DOE SRS
(803) 725-5608

Technology:
In Situ Gaseous Reduction (ISGR)
- ISGR involves injection of a low concentration H_2S gas mixture (100-200 ppmv) into soils, where it reacts with oxidized metals such as Cr^{6+} and uranium, followed by extraction of gas containing reduced metals, such as Cr^{3+}
- System included an injection pump, extraction pump, water knockout tank, scrubber, one central injection well, and six extraction wells; wells were completed to approximately 20 ft bgs
- Treatment progress was measured by breakthrough of H_2S at the extraction wells

Type/Quantity of Media Treated:
Soil (in situ)

Regulatory Requirements/Cleanup Goals:
- Objectives of demonstration were to provide technical and cost information about ISGR; obtain operational information; and determine site air flow characteristics
- No specific cleanup goals were identified

Results:
- After completion of the demonstration, soil samples were collected from nine boreholes; these results showed that nearly all the Cr^{6+} in the interval from 4 - 10 ft bgs was reduced - this zone contained clean white gypsum sand that initially contained the highest concentrations of Cr^{6+}
- The mass of Cr^{6+} did not change appreciably in the 10-16 ft bgs interval, which contained a brownish sand containing gypsum plus clay
- These results suggested that the effectiveness of ISGR is limited by subsurface heterogeneities, with channeling of the injected gases in the most permeable white sand
- Comparison of pre- and post-demonstration soil samples showed that >70% of the Cr^{6+} mass was reduced, and all post-treatment samples had <30 mg/kg of Cr^{6+}

Costs:
- Projected costs for a full-scale application of ISGR were a total cost of $798,163, or $43/yd^3
- Projected unit for ISGR were estimated to range as high as $100/yd^3, depending on the size of the waste site

In Situ Gaseous Reduction System Demonstrated at White Sands Missile Range, New Mexico

Description:
The White Sands Missile Range lies within the Mexican Highland Section of the Basin and Range Province. Contamination was discovered at SWMU 143 in January 1990 when greenish-yellow soil was found in a corner of the equipment yard. A review of facility records indicated that several 55-gallon drums of Entec 300 had spilled directly onto the ground in 1982 or 1983.

In a cooperative effort between DOE and DoD, ISGR was demonstrated at this site in the spring and summer of 1998. The technology involved injecting 200 ppm H_2S mixture into chromate-contaminated soils. Results showed that >70% of the Cr^{6+} in the soil was reduced to Cr^{3+} during the demonstration, and that all post-treatment soil samples had <30 mg/kg of Cr^{6+}. The amount of H_2S consumed during the test was greater than the amount predicted in laboratory studies, and is likely due to interfering reactions in the field or slower reaction kinetics. A life-cycle cost analysis suggested that ISGR should be a less expensive remedy than excavation, especially for sites where the depth of contamination is more than 15 - 20 ft bgs. During FY 1999-2000, a deployment is planned at the DOE Hanford site to remediate Cr^{6+}-contaminated soils in the 100 Area.

Electrokinetics at an Active Power Substation (Confidential Location)

Site Name:
Active Power Substation (Confidential Location)

Location:
Southern U.S.

Period of Operation:
Summer 1998 (6 month pilot-scale study)

Cleanup Authority:
Not identified

Purpose/Significance of Application:
First field demonstration of electrokinetic remediation in the U. S. by Electrokinetics, Inc.

Cleanup Type:
Field demonstration

Contaminants:
Heavy Metals

- Arsenic concentrations ranged from 1-1,400 mg/kg

Waste Source:
Herbicide use

Contacts:

Vendor:
Laurie LaChiusa
Vice President
Electrokinetics, Inc.
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Technology:
Electrokinetics

- Pilot-scale testing was conducted in two adjacent treatment cells – one for arsenic extraction and one for arsenic stabilization – each measuring 30 ft long by 20 ft wide by 31 ft deep (18,600 ft^3)
- Each treatment cell had three anodes spaced 10 ft apart and one cathode located 30 ft from the middle anode; the cathode was made of carbon steel and inserted to a depth of 31 ft
- In the first cell, a depolarizing agent was pumped in at the cathode to create a neutral to slightly basic catholyte
- In the second cell, proprietary reactive anodes were used to inject an arsenic-binding compound into the soil mass
- The first cell (extraction) required 80 kW-hr per yd^3; the second cell (stabilization) 74 kW-hr per yd^3; for each cell, the pH was 5 and moisture content was 25%
- Prior to the pilot-scale tests, bench-scale studies were conducted using soil samples from several substation sites located in the southeastern U.S.

Type/Quantity of Media Treated:
Soil

- Silty sands without heavy clay
- Soil properties include pH of 5 and hydraulic conductivity of 6×10^{-5} cm/sec

Regulatory Requirements/Cleanup Goals:

- Assess the performance of extraction and stabilization systems, and determine which configuration would yield the best results for extracting arsenic and preventing off-site migration

Results:

- Bench-scale test results showed that >99% of arsenic was extracted; tests of arsenic-binding compounds showed that soil passed both the TCLP and SPLP leachability tests
- A final report for the pilot-scale demonstration had not yet been submitted, and performance results are not available for release to the public
- Results are expected to be available in the first quarter of 2000

Costs:

- Cost data are not yet available for release to the public; these are expected to be available in the first quarter of 2000

Electrokinetics at an Active Power Substation (Confidential Location)

Description:
A large southern U.S. power company performed bench- and pilot-scale studies of electrokinetic extraction and electrokinetic stabilization for selected arsenic contaminated sites. After extensive analysis of both the results of bench-scale studies on representative soils and site conditions at several substations, one active power substation site (confidential location) was selected for pilot-scale electrokinetic treatment. Both electrokinetic extraction and electrokinetic stabilization configurations were explored at this site.

The pilot-scale demonstration was performed using one treatment cell for arsenic extraction, that used a depolarizing agent, and one cell for arsenic stabilization, that used proprietary reactive anodes. Results from the bench-scale tests showed extraction of >99% of the arsenic from the soil, and that soil passed both TCLP and SPLP leachability tests. Results from the pilot-scale tests are expected to be made available in the first quarter of 2000.

Electrokinetics at Site 5, Naval Air Weapons Station Point Mugu, California

Site Name:
Naval Air Weapons Station Point Mugu, Site 5

Location:
Point Mugu, California

Period of Operation:
March 1998 - June 1999

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Field demonstration of electrokinetics for treatment of metals in a sandy soil

Cleanup Type:
Field demonstration

Contaminants:
Heavy metals
- Total concentrations of chromium up to 25,100 mg/kg and cadmium up to 1,810 mg/kg
- TCLP concentrations of chromium were nondetect and cadmium were 10.5 mg/L

Waste Source:
Lagoons used for wastewater discharges from electroplating and metal finishing activities

Contacts:

Technology Researcher:
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Vendor:
Lynntech, Inc.

Technology:
Electrokinetics
- Two 1/8-acre test cells; one cell (#1) contained the two former waste lagoons and the surrounding berms, and was an artificially confined treatment area
- The second cell (#2) was an unconfined treatment area that was open to groundwater and tidal effects
- Operations within test cell #2 were never initiated due to performance problems observed in cell #1
- An electrically nonconductive sheet pile barrier wall was installed to a depth of 20 feet around the perimeter of cell #1
- Three rows of anode wells and two rows of cathode wells were installed to a depth of 10 ft; initial current density was 0.2 mA/cm^2
- By 5/98 (3 months of operation), the size of the test area was reduced (1/16 acre), and the current density was increased from 0.2 mA/cm^2 to more than 0.33 mA/cm^2
- In 10/98 (22 weeks of operation), the field demonstration was temporarily suspended
- From January to June 1999, system operation resumed in a further reduced area (approximately 500 ft^2)

Type/Quantity of Media Treated:
Soil
- Soil type was sandy soil and sediment, with 85% sand, 7% gravel, 6% silt, and 1% clay
- Soil properties included pH of 5.84, total organic carbon of 6,390 mg/kg, hydraulic conductivity of 0.045 cm/sec, and cation exchange capacity of 3.9

Regulatory Requirements/Cleanup Goals:
- Metals - meet TCLP levels and California state total threshold limit concentration, and soluble threshold limit concentration levels

Results:
- Analytical results of multiple soil and pore fluid samples were used to track the movement of heavy metals over time
- October 1998 results indicated that chromium was migrating towards the cathode
- June 1999 results indicated that cadmium was moving toward the surface and towards the cathode region, and that chromium was moving toward the cathode region
- During the demonstration, elevated levels of trihalomethanes and free chlorine were found in the electrolyte solutions

Electrokinetics at Site 5, Naval Air Weapons Station Point Mugu, California

Costs:
Not provided

Description:
The U.S. Army Environmental Center and the Engineer Research and Development Center of Waterways Experiment Station conducted a field demonstration of electrokinetics at a metal-contaminated site at Site 5 of Naval Air Weapons Station Point Mugu, California. NAWS Point Mugu comprises approximately 4,500 acres, and is located approximately 50 miles northwest of Los Angeles. Site 5, the Old Area 6 Shops, is a large area where electroplating and metal finishing operations were conducted. The area of study was approximately one-half acre in and around two former waste lagoons located in the center of Site 5. The lagoons are unlined and were used between 1947 and 1978 to receive wastewater discharge from electroplating and metal finishing activities. Prior to the field demonstration, extensive laboratory testing was conducted to assess the potential effectiveness of electrokinetic extraction at NAWS Point Mugu.

Results from laboratory studies showed that electrokinetics could successfully be applied to the demonstration site at NAWS Point Mugu. During the demonstration, electrokinetics increased the mobility of cadmium and chromium at this site. Operation of the electrokinetic extraction system at the NAWS Point Mugu site is continuing to identify and further assess the factors that limit the performance of the technology. According to USAEC, at its current stage of development, this technology is not considered to be sufficiently developed to be considered as a commercially available technology. Issues to be resolved prior to full-scale commercialization include formation of trihalomethanes; effects on naturally occurring ions; a methodology for predicting treatment performance; electrode design and its effects on electric field shape and intensity; and a methodology for determining the configuration of the electrodes under field conditions.

Electrokinetic Extraction at the Unlined Chromic Acid Pit, Sandia National Laboratories, New Mexico

Site Name:
Sandia National Laboratories (SNL), Unlined Chromic Acid Pit

Location:
New Mexico

Period of Operation:
May 15 to November 24, 1996

Cleanup Authority:
Not identified

Purpose/Significance of Application:
The first field demonstration of electrokinetics for removal of contaminant ions from arid soil

Cleanup Type:
Field demonstration

Contaminants:
Heavy metals (chromium)
- Total chromium concentrations were measured in soil as high as 200 mg/kg, up to 17 ft bgs
- TCLP chromium concentrations were measured in soil as high as 28 mg/L

Waste Source:
Waste pit

Contacts:

Technology Researcher:
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Technology:
Electrokinetics
- SNL's patented electrode - constructed of a porous, ceramic outer casing and an inner, iridium-coated titanium electrode; extracts contaminants by moving them into water held under tension (a partial vacuum) inside the outer casing
- For demonstration, three rows of electrodes in 144 ft^2 area; center row - five anodes; outer two rows - each five cathodes
- Voltage applied between electrodes - 1,572 kW hrs total; current applied to each electrode was about 15 amps
- Additional components included a liquid control system, a vacuum control system, a power application system, and a monitoring system

Type/Quantity of Media Treated:
Soil
- Near surface geology consists of alluvial fan deposits with some eolian deposits
- Sediments consist of intercalated fine-to-coarse grained, well-sorted to poorly-sorted sands, gravels, and cobbles
- Water table located 485 ft bgs
- Soil moisture content about 10 weight percent; conductivity is <10 mS/m

Regulatory Requirements/Cleanup Goals:
- Demonstrate extraction of chromate from unsaturated soils without addition of significant amounts of water

Results:
- 13 tests were performed in the demonstration (12 operating conditions; 1 system performance testing)
- A total of approximately 600 grams of hexavalent chromium were removed from the soil after 2700 hours of operation (0.22 g/hr)
- At the system's preferred operating conditions, approximately 200 grams of hexavalent chromium were removed during 700 hours of operation (0.29 g per hour)
- After treatment, soil samples adjacent to the cathodes had total chromium concentrations of 72 ppm and TCLP concentrations less than 5 mg/L
- Addition of significant amounts of water was not required

Costs:
Not provided

Electrokinetic Extraction at the Unlined Chromic Acid Pit, Sandia National Laboratories, New Mexico

Description:
Sandia National Laboratories (SNL) is located southeast of Albuquerque, New Mexico, within the boundaries of Kirtland Air Force Base. The Unlined Chromic Acid Pit is located in the Chemical Waste Landfill at SNL, which is located in Technical Area III. The chromium disposed of in the Unlined Chromic Acid Pit was in the form of chromic sulfuric acids. A chromium plume resides in the vadose (unsaturated) zone beneath the pit, with the most contaminated horizon beneath the pit containing concentrations of chromium higher than 200 mg/kg.

A field demonstration of *in situ* electrokinetic extraction technology was conducted at the Unlined Chromic Acid Pit to show that chromate could be extracted from unsaturated soils on a field scale without the addition of significant amounts of water. The field demonstration targeted the floor of the former pit at a horizon 8 to 14 feet below the surface, with three rows of electrodes placed in a 12-foot by 12-foot area. Test results met the goal, with the soil samples adjacent to the cathodes showing total chromium concentrations of 72 ppm and TCLP concentrations less than 5 mg/L. In addition, the electrokinetic process was found to be stable over long periods of time. While SNL's electrokinetic extraction system was successful in removing chromium from unsaturated sandy soil, SNL noted that the electrode system was a research prototype and was not specifically engineered for commercialization. After the 1996 field demonstration, SNL began developing a passive system, where the system is operated at a lower power, thereby avoiding the expense of actively cooling the electrokinetic electrode system. The new system uses a solid matrix capture system, eliminating the need for the liquid control and vacuum systems.

In-Situ Thermal Desorption at the Former Mare Island Naval Shipyard, California

Site Name: Former Mare Island Naval Shipyard	**Location:** California
Period of Operation: September to December 1997	**Cleanup Authority:** California EPA
Purpose/Significance of Application: Field demonstration of in situ thermal desorption to treat PCBs in shallow and deep contaminated soils	**Cleanup Type:** Field demonstration
Contaminants: PCBs • PCB levels were measured as high as 2,200 mg/kg, with an average of 220 mg/kg during a RI	**Waste Source:** Contaminated wash water discharged to soil
Contacts: **Vendors:** Mr. Gary R. Brown, P.E. Project Oversight Manager RT Environmental Services, Inc. 215 West Church Road King of Prussia, PA 19406 Telephone: 610-265-1510 Fax 610-265-0587 Email: grbrwn@aol.com Mr. Vince Fredrick, Project Manager TerraTherm Environmental Services, Inc. 19510 Oil Center Blvd. Houston, TX 77073 Telephone: 281-925-0400 Fax: 281-925-0480 Email: vfredrick@terratherm.com **U.S. Navy Contacts:** Mr. Ken Spielman EFA West, NAVFAC Code 182 900 Commodore Drive San Bruno, CA 94066 Telephone: 650-244-2539 Fax: 650-244-2553 Email: khspielman@efawest.navfac.navy.mil Mr. Chris Lonie EFD Pacific Env Restoration 258 Makalapa Dr Pearl Harbor 96860-3134 Telephone: 808-474-5962 Email: LonieCM@efdpac.navfac.navy.mil	**Technology:** In-Situ Thermal Desorption (ISTD) • Two demonstrations were conducted – a thermal well and a thermal blanket – using the MU-125 (125 cfm capacity) unit • 12 thermal/vapor extraction wells, installed to a depth of 14 ft bgs and screened from 6 inches to 14 ft, used to treat deeper soil • Two thermal blankets used to treat shallow soils • Emissions control system included a flameless thermal oxidation unit, a heat exchanger, and GAC augmented with pelletized calcium hydroxide • Heating was conducted for a total of 35 days (over a period of 3 months) to reach the target temperature of 600°F at four central monitoring locations • Process flow rates ranged from 38 to 82 scfm
	Type/Quantity of Media Treated: Soil • Aquifer material - siltstone/fine-grained sandstone • Groundwater depth - approximately 9 feet to 15 feet bgs • Moisture content - approximately 20% • Porosity - approximately 30%

In-Situ Thermal Desorption at the Former Mare Island Naval Shipyard, California

Regulatory Requirements/Cleanup Goals:

- The primary performance objective for the demonstration was to treat PCBs in soil to a concentration of less than 2 mg/kg
- Off-gas limits included an HCL emission rate limit of 4.0 lbs/hr

Results:

- All post-treatment samples had total PCB concentrations below the quantitation limit (10 ug/kg) and met the performance objective of <2 mg/kg
- On average, the thermal wells reduced total PCBs from 53,540 ug/kg to <10 ug/kg, to a 12 ft depth
- On average, the thermal blankets reduced total PCBs from 20,607 ug/kg to <10 ug/kg, to a 1 ft depth
- The HCl emission rate limit of 4.0 lbs/hr was not exceeded during the demonstration
- CO emissions were below 10 ppmV with a mean concentration of approximately 2 ppmV
- Total hydrocarbon emissions ranged from 0 to 8 ppmV with a median discharge rate of less than 0.002 lb/hr as CH_4
- Excess oxygen was ≥ 12%, except during the change over to the thermal blanket

Costs:

- Actual construction and operating costs for this project are not available
- Depending on site-specific factors, the vendor has established an overall cost range of approximately $100 to $250 per ton

Description:

The Former Mare Island Naval Shipyard includes an electrical workshop, known as Building 866, which was used from 1955 to 1994. From 1955 to 1978, transformers washed in the workshop contained polychlorinated biphenyl (PCB) oils, which were drained and washed into a 30-gallon sump through floor grates and drains. The liquid waste and sludge that accumulated in the sump were pumped to a 3,000 gallon grease trap near the western corner of the building. The test site was located in the area of the former grease trap and adjacent paved areas located at the northwest corner of Building 866. Levels of PCBs as high as 2,200 mg/kg were identified at the site during the remedial investigation. A demonstration of In-Situ Thermal Desorption (ISTD) using thermal blankets and thermal wells was conducted in this area by the U.S. Navy and the Bay Area Defense Conversion Action Team (BADCAT) Environmental Technology Project (ETP).

ISTD is a combination of thermal desorption and vacuum extraction, and is conducted in-situ. Two demonstrations were conducted (thermal well and thermal blanket) and were found to be effective in treating PCB impacted soils, achieving the performance objective of 2 mg/kg. The results of the demonstrations suggested minor modifications in well heater materials, control, and monitoring to aid in more even soil heating and extend heater life and efficiency. The heater failures experienced on this project were attributable to the use of 316 stainless steel heater strips (rather than 310 stainless steel), and the initially high operating temperature of heaters.

Soil Vapor Extraction Enhanced by Six-Phase Soil Heating at Poleline Road Disposal Area, Fort Richardson, Alaska

Site Name:
Poleline Road Disposal Area (PRDA), Operable Unit B

Location:
Fort Richardson, Alaska

Period of Operation:
Treatability Study - July through December 1997

Cleanup Authority:
CERCLA and State
Record of Decision (ROD) date - August 8, 1997

Purpose/Significance of Application:
Treatability study of SVE enhanced with SPSH to treat soil contaminated with VOCs.

Cleanup Type:
Treatability study

Contaminants:
Organic Compounds
- Volatiles (halogenated)
  - 1,1,2,2-Tetrachloroethane (TCA)
  - Tetrachloroethene (PCE)
  - Trichloroethene (TCE)
  - Maximum concentrations: 2,030 mg/kg TCA, 159 mg/kg PCE, 384 mg/kg TCE

Waste Source:
Chlorinated solvents were used as a carrier for neutralization chemicals after burning of materials in disposal trenches

Contacts:

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Technology:
Soil Vapor Extraction (SVE) with Six-Phase Soil Heating (SPSH)
- Electrical power was delivered to the soil by steel electrodes inserted vertically in a circular array. Each electrode served as an SVE vent
- Electric current passed through the soil creating steam and contaminant vapors
- A blower pulled soil vapors from the SVE vents and through a knockout tank to a condenser
- The condenser cooled and condensed hot vapors and separated the gas and liquid phases
- The gas phase passed through a knockout tank and was discharged to the atmosphere
- The liquid stream was treated by air stripping and was discharged on site

Type/Quantity of Media Treated:
- 3,910 cubic yards or 7,150 tons of soil in situ
- Soil Moisture Content: 7.3 – 13.9%
- Air Permeability (within the soil volume): 1.6×10^{-7} cm^2
- Soil Porosity: 21 – 27%

Soil Vapor Extraction Enhanced by Six-Phase Soil Heating at Poleline Road Disposal Area, Fort Richardson, Alaska

Regulatory Requirements/Cleanup Goals:
- System performance was evaluated against three primary criteria:
  1. The ability of each of the three six-phase heating arrays to heat soil in-situ
  2. Demonstrated removal of contaminants, as measured in the condenser off-gas and condensate
  3. Demonstrated reduction of soil contamination, as measured in the pre- and post-treatment soil samples
- The air stripper effluent was compared to the Alaska maximum contaminant levels (MCLs) for drinking water

Results:
- The treatability study met all of the criteria established for system performance
- The air stripper effluent met Alaska MCLs

Costs:
- The total cost for this project was $967,822
- The total cost for treatment ranged from $189 to $288 per CY ($103 to $158 per ton) of soil. The soil treatment costs ranged from $726 to $2,552 per pound of contaminant removed
- The large power requirement of the treatment equipment was a significant operating cost because the site was in a remote location and power was provided by diesel generators

Description:
The PRDA was active from approximately 1950 to 1972. Chlorinated solvents were used as a carrier for neutralization chemicals that were applied after burning of materials in disposal trenches. These materials included chemical warfare agents, smoke bombs, and Japanese cluster bombs (detonated prior to burial). Four disposal areas have been identified in an area encompassing approximately 1.5 acres. Two solvents, TCA and TCE, were found in higher concentrations and over a larger area than any other chemicals detected. PCE was also detected above action levels. A 1996 treatability study at the PRDA concluded that SVE was capable of removing solvent vapors from the subsurface, but at a rate that would require more than 10 years of treatment. Based on these results, it was recommended that SVE treatment enhanced with in-situ soil heating could be used at the site as a means for completing treatment more rapidly.

A treatability study was conducted between July and December 1997 to evaluate SVE enhanced by SPSH. Three arrays were constructed and operated at PRDA. Two arrays were 27 feet in diameter and one array was 40 feet in diameter. Each array was operated for six weeks after a shakedown period. The smaller arrays demonstrated over 90% removal of soil contaminants; the larger array demonstrated over 80% removal of contaminants. These results indicated that there may be limitations to the size of the array that can effectively treat soil at a particular site. The size of the array is limited by the resistivity of the soil and power requirements.

Phytoremediation at Argonne National Laboratory – West, Waste Area Group 9, Operable Unit 9-04, Idaho Falls, Idaho

Site Name:
Argonne National Laboratory – West, Waste Area Group 9, Operable Unit 9-04

Location:
Idaho Falls, Idaho

Period of Operation:
May to October 1998

Cleanup Authority:
CERCLA
- ROD dated 9/29/98

Purpose/Significance of Application:
Bench-scale testing of phytoremediation to treat heavy metals in soil

Cleanup Type:
Bench scale

Contaminants:
Heavy metals
- Contaminants of concern included chromium, mercury, selenium, silver, and zinc.
- Soil concentrations are 44.85 mg/kg Cr, <1.5 mg/kg total Hg, and 56.32 mg/kg total Zn

Waste Source:
Scientific and engineering research activities

Contacts:

Technology Provider:
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Site Contact:
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Technology:
Phytoremediation
- Greenhouse experiments were performed using contaminated soil and clean sand
- Three candidate plant species were tested: Prairie Cascade hybrid willow; canola; and kochia
- For the soil experiment, the soil was spiked with EDTA and citric acid
- For the sand experiment, the soil was spiked with metals (soluble forms of Cr, Zn, Hg, Ag, and Se)

Type/Quantity of Media Treated:
Soil
- Site is a relatively flat, semi-arid, sagebrush desert
- Climate conditions are a temperature range of 7.9°F - 84.8°F; a growing season of April to mid-October; and annual average precipitation of 8.7 inches
- Soil texture is loam, with particle size distribution of 47% sand, 34.6% silt, 18.4% clay
- Soil composition is 1.59% organic matter, 5.41% lime, 5,310 mg/kg extractable Ca, 510 mg/kg extractable Mg, 76 mg/kg extractable Na, 438 mg/kg extractable K, 48 mg/kg extractable P, 71 mg/kg soluble SO_4, and 76 mg/kg soluble Na; soil pH is 8.57

Regulatory Requirements/Cleanup Goals:
- Determine uptake rates and metal concentration factors for each plant species
- Determine the most effective, non-hazardous chelating agent to increase the availability of metals from impacted soils
- Evaluate potential maximum uptake of metals by candidate plant species under selected conditions

Results:
- The optimum formulation of chelating agents for treating the metals was determined to be a 0.05 molar solution of 40% EDTA and 60% citric acid
- In the sand experiment, the best recovery levels for zinc, chromium, mercury, and silver were found in the willow with 96%, 38%, 42%, and 24% recovery, respectively
- Testing using actual soils yielded significantly lower removals than with the sand experiment; the amount of zinc and chromium removed was 4-5% and 2%, respectively
- The willow roots had better removal of the metals than either kochia or canola
- It was concluded that willows would be used in the field; possible removal rates of up to 14% of Zn and 3 to 4% Cr per year were predicted, which could result in cleanup times between 6 - 7 years for Zn and 9 years for Cr

Phytoremediation at Argonne National Laboratory – West, Waste Area Group 9, Operable Unit 9-04, Idaho Falls, Idaho

Costs:

- Use of phytoremediation at full-scale for four sites at ANL-W was projected to cost $2,247,000, including management - $528,000; documentation - $98,000; construction - $841,000; and O&M - $780,000
- The construction cost consisted of an initial 2-year field test at $300,000 and a contingency of $542,000 for five additional years of phytoremediation

Description:

The Idaho National Engineering and Environmental Laboratory (INEEL), located in Idaho Falls, Idaho, is a government facility managed by the U.S. DOE. Various sites at ANL-W are contaminated with wastes generated from the scientific and engineering research at ANL-W and contain various levels of petroleum products, acids, bases, PCBs, radionuclides, and heavy metals. The ROD for Waste Area Group 9 identifies seven areas that will undergo remediation and identifies phytoremediation as the remedy, with a contingent remedy of excavation and disposal. As a pre-condition for implementing phytoremediation in these areas, bench scale (laboratory and greenhouse) tests were performed to evaluate the applicability of phytoremediation as well as to determine operating parameters and time frames for full-scale implementation

The bench-scale tests were conducted in a greenhouse using contaminated soil and sand that was spiked with metals. Results from these tests showed that use of contaminated soils yielded significantly lower removals than sand, with removals from soil of chromium - 2% and zinc - 4 to 5%, and that willows were the best species for use at the site. Based on these results, ANL-W calculated the number of years of phytoremediation that would be required to meet the remediation goals for several site areas, and these estimates ranged from 6 to 122 years. As a next step, each of five sites at ANL-W will be treated using phytoremediation during a two-year field test. Each site will be planted with three-foot tall bare-root willow trees in a grid pattern, and whole tree harvesting (roots and above ground) will occur at the end of each growing season. Excavated trees will be chipped and transported to an on-site incineration facility for disposal.

Phytoremediation at the Open Burn and Open Detonating Area, Ensign-Bickford Company, Simsbury, Connecticut

Site Name:
Ensign-Bickford Company, Open Burn and Open Detonating Area

Location:
Simsbury, Connecticut

Period of Operation:
April - October 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Phytoremediation of lead in soil using both phytoextraction and phytostabilization

Cleanup Type:
Full scale

Contaminants:
Lead
- Average concentration of total lead was 635 mg/kg; concentrations were higher than 1,000 mg/kg in many areas of the site, with some areas exceeding 4,000 mg/kg
- Leachable lead concentrations were higher than 0.015 mg/L using the Synthetic Precipitation Leaching Procedure (SPLP)

Waste Source:
Open burn and open detonation

Contacts:

Vendor:
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Fax: (703) 390-1180
E-mail: SoilRx@aol.com

Technology:
Phytoremediation
- Combination of phytoextraction (for treatment of four areas with high lead concentrations - Areas 1-4) and phytostabilization (for treatment of one area with low lead concentrations - Area 5) to reduce total soil lead concentrations and SPLP extractable lead
- Soils were fertilized with nitrogen, phosphorus, and potassium; dolomite lime was added to adjust soil pH
- Fertilizers and lime were tilled into the soil to a depth of 15 to 20 cm; an overhead irrigation system was used to provide moisture
- Areas 1-5 were seeded with Indian mustard and sunflower; 3 treatment crops were planted
- Supplemental foliar fertilizers were added through the irrigation system
- Area 5 also treated with stabilizing amendments

Type/Quantity of Media Treated:
Soil
- Soil type is silty loam with a pH of 6.5 to 7.5
- Water table ranges in depth from 2 to 4 ft below surface soil
- Site drainage is poor; soil remains saturated throughout the growing season (April to October)

Regulatory Requirements/Cleanup Goals:
- Reduce total lead concentrations; specific cleanup levels not identified

Results:
- Plant growth for each of the treatment crops was generally good
- Some areas within the treatment area remained saturated; these areas exhibited poor plant growth and reduced biomass yields
- Total lead concentrations in Areas 1-4 decreased from an average of 635 mg/kg (4/98) to 478 mg/kg (10/98); by 10/98, the highest concentrations in Areas 1-4 had been reduced
- Lead uptake ranged from 342 mg/kg (dry weight) in the Indian mustard in treatment crop 1 to 3252 mg/kg in the Indian mustard in treatment crop 3
- Average lead uptake measured in the sunflower plant material and Indian mustard were similar, having average lead concentrations from all crops of approximately 1000 mg/kg (dry weight).
- The average reduction in SPLP lead concentration in Area 5 was 0.95 mg/L.

Costs:
Not provided

Phytoremediation at the Open Burn and Open Detonating Area, Ensign-Bickford Company, Simsbury, Connecticut

Description:
The Ensign-Bickford Company in Simsbury, Connecticut, conducted open burn/open detonation (OB/OD) activities, resulting in near surface soils in the area becoming contaminated with lead. From 1996 to 1997, Edenspace Systems Corp. (formerly known as Phytotech, Inc.) conducted phytoremediation treatment of a 1.5 acre area surrounding the OB/OD area. In 1998, this effort was expanded to include a total of 2.35 acres and to address not only reductions in total lead concentrations, but also stabilizing leachable lead in the soil.

Phytoremediation was conducted using three treatment crops of Indian mustard and sunflower over a six month period. Total lead concentrations in a portion of the site decreased from an average of 635 mg/kg (4/98) to 478 mg/kg, with hot spots also reduced. In the area where phytostabilization also was used, the average reduction in SPLP lead concentration was 0.95 mg/L. Further treatment is planned during 1999 and 2000.

Phytoremediation at Twin Cities Army Ammunition Plant, Minneapolis-St. Paul, Minnesota

Site Name:
Twin Cities Army Ammunition Plant (Site C and Site 129-3)

Location:
Minneapolis-St. Paul, Minnesota

Period of Operation:
Spring and Summer 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Phytoremediation of heavy metals in soil in a northern climate

Cleanup Type:
Field demonstration

Contaminants:
Heavy metals
- Site C: antimony, arsenic, beryllium, lead, and thallium; average of 2,610 ppm lead in surface soil
- Site 129-3: antimony, barium, chromium, and lead; average of 358 ppm lead in surface soil

Waste Source:
Burn areas, pits used for wastewater disposal

Contacts:

Technology Contact:
Ms. Darlene F. Bader
U.S. Army Environmental Center
SFIM-AEC-ETD (Bader
5179 Hoadley Road, Bldg E4430
Aberdeen Proving Ground, MD
21010-5401
Telephone: (410) 436-6861
E-mail: t2hotline@aec.apgea.army.mil

Technology:
Phytoremediation
- Demonstration used 0.2-acre plots at Site C and Site 129-3
- Sites were prepared by clearing, fencing, plowing, and installing an irrigation system
- Two crops were grown on each site; first corn and second white mustard
- Amendments (acetic acid and EDTA) were added to the soil to aid in the solubilization and uptake of lead
- Each crop was harvested and smelted

Type/Quantity of Media Treated:
Soil
- Climate conditions included an average annual precipitation rate of 28.6 inches and an average annual temperature of 49.6°F; the location also can have early/late frosts
- Soil type at Site C is peat, underlain by fine sand and sandy clay; at Site 129-3, fine- to medium-grained sand
- Depth to water table at Site C is 2 to 6 ft bgs; at Site 129-3, 140 to 200 ft bgs

Regulatory Requirements/Cleanup Goals:
- Determine if phytoextraction is a technically and economically feasible means of reducing lead contamination from near-surface soils; specific cleanup levels not identified

Results:
- Results from the first year's demonstration showed less than anticipated biomass yields and lead uptake in the harvested plant material
- Corn yielded 2.1 to 3.6 tons per acre, compared to the anticipated yield of 6.0 tons per acre; poor yields were attributed to agronomically low producing soils at the site and the presence of other soil contaminants
- Lead concentrations in harvested corn averaged 0.65% and 0.13% dry weight for Sites C and 129-3, compared with the 0.85% removal obtained during a prior greenhouse study
- White mustard yielded 1.9 to 2.1 tons per acre; on a per plot basis, the total yields for Site C were half of this value since the white mustard grew in only about 50% of the plot area
- In the areas where plants grew, the yields were comparable to the expected yield of 2 tons per acre of mustard
- Lead concentrations in harvested white mustard averaged 0.083% and 0.034% dry weight for Sites C and 129-3, compared with the 1.5% obtained during greenhouse studies

Phytoremediation at Twin Cities Army Ammunition Plant, Minneapolis-St. Paul, Minnesota

Costs:

- USAEC developed a preliminary cost estimate for a typical full-scale phytoextraction project in a northern U.S. location, with two crops grown per year (one corn and one white mustard), sub-optimal soil conditions for plant growth, soil lead levels of about 2,500 ppm, and five years of remediation required to meet the regulatory standard
- The projected cost for full-scale phytoextraction was $30.34 per cubic yard of soil per year, or about $153 per cubic yard of soil over the life of the project

Description:

The Twin Cities Army Ammunition Plant (TCAAP) is a 2,370-acre facility located in Arden Hills, Minnesota, approximately 10 miles north of Minneapolis-St. Paul, Minnesota. The TCAAP was used for the production and storage of small arms ammunition, related materials, fuzes, and artillery shell materials. A phytoremediation demonstration was conducted at areas within Sites C and 129-3 at the TCAAP. Site C was used for burning production materials and decontamination equipment. Site 129-3 contained pits that were believed to have contained contaminated wastewater from a lead styphanate production facility. The project is a two-year field demonstration executed under a partnering agreement among the U.S. Army Environmental Center (USAEC), Tennessee Valley Authority (TVA), TCAAP, and the U.S. Army's Industrial Operations Command (IOC).

During the first year, phytoremediation was conducted at thee sites using corn and white mustard, and results were less than anticipated. Changes planned for 1999 to improve performance included use of alternate mustard varieties; use of higher fertilizer rates to encourage greater biomass; varying the irrigation scheme to encourage rooting and growth; alternate amendment delivery systems; deep tilling; and alternate EDTA degradation methods.

EG&G's ™ Aerobic Biofiltration System for the Destruction of Hydrocarbon Vapors from Fuel-Contaminated Soils

Site Name: Patrick Air Force Base, Active Base Exchange (BX) Service Station	**Location:** Florida
Period of Operation: 1/15/94 to 2/26/94	**Cleanup Authority:** RCRA UST
Purpose/Significance of Application: Treatment of extracted vapors from an SVE system	**Cleanup Type:** Field demonstration
Contaminants: Volatile hydrocarbons and BTEX • Initial soil gas contained TVH of 2,400 ppmv in study area	**Waste Source:** Leaks from USTs
Contacts: **Vendor:** EG&G Rotron Division Saugerties, NY **Air Force Contact:** U.S. Air Force Center for Environmental Excellence Technology Transfer Division Brooks AFB, TX	**Technology:** Biocube™ (supplement to SVE) • Demonstration used an above-ground biofiltration unit, consisting of a proprietary mixture of inorganic and organic substrate containing active bacteria • Unit removed hydrocarbons by adsorption and biodegradation • Soil vapors from a horizontal vent well at 4 ft bgs passed through knockout drum and diluted with fresh air to maintain an influent concentration of 1,000 ppm, then passed through a humidifier prior to the Biocube™ • A recirculation loop was installed to allow multiple passes through the biofilter • Air emissions from the biofilter were passed through vapor-phase carbon prior to discharge; three 55-gal drums were used **Type/Quantity of Media Treated:** Soil vapors • Average depth to water table is 5 ft

Regulatory Requirements/Cleanup Goals:

- Test objectives were to remove BTEX - >90% and TVH - >75%, based on an influent concentration of 1,000 ppmv

Results:

- In first 8 days of operation, at a flow rate of 30 scfm, no measurable differences were detected between Biocube™ influent and effluent, and the system was reconfigured
- Maximum removal efficiencies of 90.8% for BTEX and 29.5% for TVH were achieved at very low loading rates and flow rate of 3.2 scfm
- At a 49 scfm flow rate, removal efficiencies were BTEX of 40% and TVH of 18%
- Limitations experienced during the demonstration included a relatively slow system acclimation; vacuum leaks and dilution of process gas; and inaccurate flow measurements

Costs:

- Full-scale cost estimates were not provided based on this demonstration
- Costs provided by other biofiltration vendors showed unit costs of \$18.66/kg to \$38.06/kg, for TVH influent concentrations of 1,000 to 2,000 ppmv and flow rates of 20 - 40 scfm

EG&G's ™ Aerobic Biofiltration System for the Destruction of Hydrocarbon Vapors from Fuel-Contaminated Soils

Description:
A field demonstration of the Biocube™ aerobic biofiltration system technology was conducted at Patrick Air Force Base in Florida to determine the effectiveness of the technology in reducing VOCs in extracted soil vapors prior to release to the atmosphere. The Biocube™ demonstration was tested on the soil vapors extracted from a single extraction well at the Base Exchange service station.

The target removal efficiencies could be achieved only when the flow rate and loading were reduced to impractically low levels. As such, the Biocube™ could not be used as the primary vapor treatment technology when high BTEX and TVH removal efficiencies were required.

Internal Combustion Engines for the Destruction of Hydrocarbon Vapors from Fuel-Contaminated Soils

Site Name:
Patrick Air Force Base, Active Base Exchange (BX) Service Station

Location:
Florida

Period of Operation:
10/18/93 to 1/14/94

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Use of an internal combustion engine to treat extracted vapors from an SVE system

Cleanup Type:
Field demonstration

Contaminants:
Volatile hydrocarbons
- Initial soil gas contained TVH - 26,800 ppmv; benzene - ND; toluene - 15 ppmv; ethylbenzene - 14 ppmv; xylenes - 200 ppmv; concentrations decreased after these initial levels were measured
- Low levels of oxygen and BTEX were found in the soil vapors

Waste Source:
Leaks from USTs

Contacts:

Vendor:
Tom Davis
VR Systems
Anaheim, CA
Telephone: (714) 826-0483
Fax: (714) 826-8746

Air Force Contact:
U.S. Air Force
Center for Environmental Excellence
Technology Transfer Division
Brooks AFB, TX

Technology:
Internal combustion engine (ICE, as a supplement to SVE)
- Demonstration used a VR Systems Model V3 Ford Motor Company 460 in^3 displacement engine, 55-gallon knockout drum prior to engine, and onboard computer
- Horizontal vent well installed at 4 ft bgs as part of a bioventing pilot test, and used in vapor extraction mode for demonstration
- During ICE demonstration, flow rate of 150 scfm and average engine speed of 1,790 rpm used for first 2 days, followed by a flow rate of 80 scfm
- Propane used as supplemental fuel; 1,925 ft^3 used in first 2 days

Type/Quantity of Media Treated:
Soil vapors
- Average depth to water table is 5 ft

Regulatory Requirements/Cleanup Goals:
- The objectives of the demonstration included evaluating the performance and cost of the ICE technology

Results:
- Destruction efficiency was >99% for BTEX and >96% for TVH throughout the test period
- A 4% reduction in TVH destruction efficiency occurred when the engine rings and valves began to wear, allowing a portion of the propane to pass unburned through the exhaust

Costs:
- Average operating cost was $325/day for first 5 days of operation, including equipment rental, propane, and labor
- Over the course of the test, operating costs ranged from $0.83 to 15.40/kg TVH destroyed, and $97 to 550/kg of BTEX destroyed
- Costs varied based on soil vapor concentrations and supplemental fuel requirements

Internal Combustion Engines for the Destruction of Hydrocarbon Vapors from Fuel-Contaminated Soils

Description:
A field demonstration of an internal combustion engine (ICE) technology for extracted soil vapors was conducted at Patrick Air Force Base in Florida. In Florida, soil vapor extraction must include a vapor treatment technology capable of removing 99% of the VOCs prior to discharge. The ICE demonstration was tested on the soil vapors extracted from a single extraction well at the Base Exchange service station.

The ICE tested was a Ford Motor Company 460 in^3 displacement engine; it was preceded by a 55-gallon knockout drum. An onboard computer was used to control system operation. For the demonstration, the initial flow rate was 150 scfm with an average engine speed of 1,790 rpm, followed by a flow rate of 80 scfm for the remainder of the demonstration. Propane was used as supplemental fuel. The destruction efficiency measured was >99% for BTEX and >96% for TVH throughout the test period. The researchers found that initial soil gas oxygen levels were low, and they had to adjust flow rates to maintain an adequate oxygen/fuel ratio. According to the researchers, ICE technology is most effective when initial soil gas TVH is greater than 40,000 ppm, when the unit can operate without supplemental fuel.

Purus PADRE® Regenerative Resin System for the Treatment of Hydrocarbon Vapors from Fuel-Contaminated Soils

Site Name:
Vandenberg Air Force Base, Base Exchange (BX) Service Station

Location:
Lompoc, CA

Period of Operation:
2/11/94 to 6/1/94

Cleanup Authority:
Santa Barbara County Air Pollution Control District
California Department of Toxic Substances
Central Coast Regional Water Quality Control Board

Purpose/Significance of Application:
Use of resin adsorption to treat extracted vapors from an SVE system

Cleanup Type:
Field demonstration

Contaminants:
Petroleum hydrocarbons and BTEX

- Maximum concentrations in soil: TPH-gasoline - 22,000 mg/kg; benzene - 210 mg/kg; toluene - 2,000 mg/kg; ethylbenzene - 490 mg/kg; xylenes - 2,900 mg/kg
- Maximum concentrations in soil gas: volatile hydrocarbons - 54,000 ppmv; benzene - 400 ppmv

Waste Source:
Leaks from USTs

Contacts:

Vendor:
Purus Inc.
2713 N. First Street
San Jose, CA 95134-2000

Air Force Contact:
U.S. Air Force
Center for Environmental Excellence
Technology Transfer Division
Brooks AFB, TX

Technology:
Resin Adsorption (as a supplement to SVE)

- Demonstration used a Purus Padre® Model 1.6 vapor treatment system to treat hydrocarbon vapors removed using soil vapor extraction (5 SVE wells; flow rates 20 - 49 scfm)
- System used filter beds filled with synthetic polymeric adsorbent (PurSorb - 200); preceded by a water and dirt trap; two beds were used with 180 lbs adsorbent/bed; beds were switched between adsorption and desorption cycles
- In the desorption cycle, organic material was volatilized, condensed, and transferred to a tank; 2-stage condenser operated at 2°C and −45°C
- Treated soil gas with less than 1,000 ppm total hydrocarbons was returned to the soil using a perimeter injection trench for in situ biotreatment

Type/Quantity of Media Treated:
Soil vapors

- Contamination found within a permeable silty sand, extending from 3 to 14 ft bgs
- Depth to groundwater varies from 7 to 9 ft bgs and fluctuates seasonally
- Impermeable clay bed located between 14 and 20 ft bgs
- Soil vapor depleted of oxygen due to fuel biodegradation

Regulatory Requirements/Cleanup Goals:

- Objectives of the demonstration included evaluating the performance and cost of the Purus Padre® technology
- No air emission permit was required; instead operating conditions were established for ambient air, flux emissions, and site emissions

Results:

- Average soil vapor concentrations reduced by factor of five during first 18 days of treatment and by factor of 20 during 110 days of operation, with increase in oxygen content
- Resin system removal rates averaged > 98% for total hydrocarbons and >99% for benzene
- The system recovered approximately 570 gallons of hydrocarbons (1,600 kgs; 3,520 lbs) and 70 gallons of water during the 110 day demonstration

Purus PADRE® Regenerative Resin System for the Treatment of Hydrocarbon Vapors from Fuel-Contaminated Soils

Costs:

- Demonstration costs were $36,634, consisting of setup - $2,500; rental - $25,667; operation labor - $4,500; power - $1,212; nitrogen - $1,760; and mobilization/demobilization - $1,000
- Total treatment cost corresponded to a unit cost of $23/kg ($10.45/lb) of hydrocarbons removed
- A comparison of technologies showed that internal combustion engine technology will be less expensive that Purus Padre® at fuel spill sites

Description:

In 1985, two 10,000 gallon unleaded gasoline tanks and associated piping were removed from the Vandenburg AFB BX service station. Two additional gasoline storage tanks and a 250-gallon waste oil tank were removed in 1991. Hydrocarbon contamination was discovered in soil and groundwater beneath the tanks. A two-phased bioventing pilot test began on February 11, 1994. During phase one, high levels of hydrocarbon vapors were removed using soil vapor extraction, treated using a Purus Padre® resin adsorption unit, and returned to the soil using a perimeter injection trench for in situ biotreatment. When the average soil gas concentrations had been reduced to less than 1,000 ppmv, the Purus Padre® unit was removed and soil gas returned directly through the trench.

This demonstration used a Purus Padre® Model 1.6 vapor treatment system to treat hydrocarbon vapors removed using five soil vapor extraction wells, with a total flow rate of 20 - 49 scfm. The system used filter beds filled with PurSorb - 200; 180 lbs adsorbent/bed were used. System removal rates averaged > 98% for total hydrocarbons and >99% for benzene, and recovered approximately 570 gallons of hydrocarbons (1,600 kgs). Demonstration costs were $36,634, corresponding to a unit cost of $23/kg of hydrocarbon removed. This system was found to be an effective method of controlling vapor emissions.

Barometrically Enhanced Remediation Technology (BERT^{TM}) Demonstration at Idaho National Engineering and Environmental Laboratory, RWMC, Pit 2, Idaho Falls, Idaho

Site Name:
Idaho National Engineering and Environmental Laboratory, Radioactive Waste Management Complex, Pit 2

Location:
Idaho Falls, Idaho

Period of Operation:
December 1996 to January 1999

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstrated use of passive soil venting for remediation of VOC-contamination

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated solvents
- Maximum concentration of carbon tetrachloride was 111 ppm

Waste Source:
Waste burial pit

Contacts:

Technical Contacts:
William E. Lowry
Science and Engineering Associates, Inc.
(505) 424-6955
E-mail: blowry@seabase.com

Eric Miller
Lockheed Martin Idaho Technologies Company
(208) 526-9410
E-mail: ecm@inel.gov

Management Contacts:
William Haslebacher
Federal Energy Technology Center
(304) 285-5435
E-mail: whasle@fetc.doe.gov

Technology:
Barometrically Enhanced Remediation Technology (BERT^{TM})
- BERT^{TM} consists of a large surface area seal, a collection plenum, and a one-way valve to vent soil gas to the atmosphere at a low rate; the system operation relies on small changes in atmospheric pressure and wind effects to displace soil gas
- The system at INEEL used a surface seal 100 ft by 100 ft made of 45-mil EPDM, a collection plenum filled with ¼ to ½ inch pea gravel that was 10 ft thick and 30 ft diameter, and a vent pipe 6 ft tall
- In October 1996 (after almost 2 years of operation), the system was modified to extend the collection plenum to the edges of the surface seal to expose more soil; this was referred to as the wind-enhanced configuration
- No boreholes or site electrical power was used in the demonstration

Type/Quantity of Media Treated:
Soil (in situ)
- Surface soils are typically less than 20 ft thick and consist of gravelly sand and fine-grained eolian deposits; water table is 600 ft bgs

Regulatory Requirements/Cleanup Goals:
- Objectives of demonstration were to obtain technical and cost information about BERT^{TM}
- No specific cleanup goals were identified

Results:
- During the initial phase of the demonstration, the average vent flow rate was 9 m^3/day, with contaminants removed as follows: TCE - 27.8 ppm and 1.15 g/day, CCl_4 - 5.2 ppm and 0.25 g/day, and chloroform - 19.6 ppm and 0.73 g/day
- During the wind-enhanced phase of the demonstration, the average vent flow rate was 34 m^3/day, with contaminants removed as follows: TCE - 18.9 ppm and 2.9 g/day, CCl_4 - 6.8 ppm and 1.2 g/day, and chloroform - 9.4 ppm and 1.3 g/day
- Results showed that wind speed had a greater effect on vent flow than did changes (drop) in atmospheric pressure

Barometrically Enhanced Remediation Technology (BERT^{TM}) Demonstration at Idaho National Engineering and Environmental Laboratory, RWMC, Pit 2, Idaho Falls, Idaho

Costs:

- Projected costs for a full-scale application of BERT^{TM} were $67,860 total, including materials, labor, and O&M, or $100/yd^3 ($74/ton)
- Unit costs for BERT^{TM} were compared with costs for landfill disposal ($320/yd^3, $237/ton), soil vapor extraction ($183/yd^3, $136/ton), and thermal desorption ($360/yd^3, $267/ton), and found to be lower on both a per cubic yard and per ton basis

Description:

The Idaho National Engineering and Environmental Laboratory (INEEL) Radioactive Waste Management Complex (RWMC) contains a Subsurface Disposal Area (SDA). The SDA is a 96 acre fenced disposal area where mixed wastes containing VOCs and radioactive wastes were buried in shallow waste disposal pits, trenches, and soil vault rows. Disposal pit 2 at the SDA received barrels of sludge between 1954 and 1965. The primary contaminant in this area was chlorinated solvents.

The Barometrically Enhanced Remediation Technology (BERT^{TM}) was demonstrated at this site. BERT^{TM} induces net upward displacement of soil gas based on small changes in atmospheric pressure and wind speed. A system was demonstrated that was 100 ft long by 100 ft wide, and that required no boreholes or site power. During the initial phase of the demonstration, the average vent flow rate was 9 m^3/day, with removals of TCE, CCl_4, and chloroform ranging from 0.25 to 1.15 g/day. During the wind-enhanced phase of the demonstration, the average vent flow rate was 34 m^3/day, with removals of TCE, CCl_4, and chloroform ranging from 1.2 to 2.9 g/day. Results showed that wind speed had a greater effect on vent flow than changes/drops in atmospheric pressure. Unit costs for BERT^{TM} were compared with costs for landfill disposal, soil vapor extraction, and thermal desorption, and found to be lower on both a per cubic yard and per ton basis. A BERT^{TM} system is currently under construction at Los Alamos National Laboratory, with operation anticipated by the end of July 1999.

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INCINERATION ABSTRACTS

On-Site Incineration at Weldon Spring Ordnance Works, St. Charles County, Missouri

Site Name:
Former Weldon Spring Ordnance Works (WSOW), Operable Unit 1

Location:
St. Charles County, Missouri

Period of Operation:
- Trial Burn - 8/14/98 to 8/16/98
- Interim Operation - 8/17/98 to 9/18/98
- Full-Scale Operation - 9/19/98 through 1999

Cleanup Authority:
CERCLA and State
Record of Decision (ROD) date - May 1996

Purpose/Significance of Application:
Full-scale, on-site incineration of explosives and propellants

Cleanup Type:
Full scale

Contaminants:
Explosives/Propellants
- 2,4,6-Trinitrotoluene (TNT) and 2,4- and 2,6-Dinitrotoluene (DNT)
- Maximum concentrations:
  - 510,632 mg/kg TNT
  - 7,100 mg/kg 2,4-DNT
  - 200 mg/kg 2,6-DNT
- Some soil contaminated by lead, asbestos, PCBs, and PAHs

Waste Source:
Discharge and leaks/spills of contaminated wash water and wastewater; open burning of explosives

Contacts:

Project Management:
Mr. Dan Mroz
USACE, Kansas City District
USACE-MD-H
601 E. 12th Street
Kansas City, KS 64106
(816) 983-3567

Captain Jim Workman
USACE
Big Piney Building 1018
P.O. Box 200
Ft. Leonard Wood, MO 65473
(314) 498-5176

Vendor:
Mr. Alan J. Zupko
Roy F. Weston, Inc.
1 Weston Way
West Chester, PA 19380-1499
(610) 701-3623

Regulatory Contacts:
Mr. Tom Lorenz
U.S. EPA Region 7
726 Minnesota Avenue
Kansas City, KS 66101
(913) 551-7292

Mr. Ray Strebler
Missouri Department of Natural Resources,
Hazardous Waste Program,
Division of Environmental Quality
P.O. Box 176
Jefferson City, MO 65102-0176
(573) 751-7241

Technology:
On-Site Incineration
- Excavated pipeline and combustible debris were shredded
- Soil and shredded materials were fed through a screen to remove large debris
- The incineration system consisted of a co-current, rotary kiln and a secondary combustion chamber (SCC)
- The kiln operated at an exit gas temperature above 1626 °F and the SCC operated above 1823°F
- Hot gases exiting the SCC passed through a two-stage spray tower and two pulse-jet baghouses in parallel
- Treated soil and fly ash were stockpiled for compliance sampling
- Treated soil and fly ash that met treatment standards were used as fill material at the site

Type/Quantity of Media Treated:
- An estimated 30,000 tons (18,000 cubic yards) of nitroaromatics-contaminated soil
- An estimated 85,230 linear feet of nitroaromatics-contaminated wooden pipeline
- Average Moisture Content: 18%
- BTU Value: 60 Btu/lb
- Pipeline: 1 linear foot weighed approximately 25 pounds; the shredded density was 0.43 tons/CY

On-Site Incineration at Weldon Spring Ordnance Works, St. Charles County, Missouri

Regulatory Requirements/Cleanup Goals:

- Destruction and Removal Efficiency (DRE) of 99.99% for POHC
- Regulatory limits for treated soil and fly ash after incineration were 57 ppm TNT and 2.5 ppm 2,4- and 2,6-DNT
- Treated soil and fly ash with TCLP values in excess of 5 mg/L lead were stabilized
- Air emission requirements included control of metals, hydrogen chloride, chlorine, 2,3,7,8-tetrachlorinated dibenzo-p-dioxin toxic equivalents, carbon monoxide, total hydrocarbons, nitrous oxides, particulate matter and opacity in the stack gas

Results:

- Sampling of treated soil and fly ash indicated that the soil and pipeline cleanup goals were met
- Emissions data from the trial burn, interim operations and full-scale operations indicated that all emissions standards were met

Costs:

- The total cost for this project was $13,665,997 including all remedial activities performed at the site, including incineration

Description:

The former Weldon Spring Ordnance Works included a nitroaromatics manufacturing facility operated by the Army between 1941 and 1945. Wash water and wastewater generated in the TNT and DNT production plants were discharged to settling lagoons at the WSOW prior to mid-1942 and to wastewater treatment plants via an underground wooden pipeline after mid-1942. Leaks and spills occurred at the production buildings and the wastewater pipeline. Open burning was used to dispose and/or treat off-specification material, surplus product and contaminated soil. Nitroaromatics were detected in surface soil, shallow subsurface soil, groundwater and springs at the former WSOW. A ROD was signed in September 1996, specifying on-site incineration as the remedial technology for addressing nitroaromatics-contaminated soil and wooden pipeline at the site. Contaminated soil and pipeline at the former WSOW was identified as Operable Unit (OU) 1. Site cleanup goals were specified in the ROD.

Site work for construction of the incinerator was commenced in December 1997. Incinerator start up and shake down were performed in July and August 1997. The trial burn was conducted in August 1998. After receiving approval from EPA and MDNR of the proposed operating limits, the incinerator was put into full-scale operation in September 1998. Treatment was completed in April 1999. The incineration system consisted of a co-current, rotary kiln followed by a SCC. After confirming that treated soil and fly ash met the cleanup criteria, the materials were backfilled at the site. Demobilization of the incinerator from the site was completed in 1999.

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THERMAL DESORPTION ABSTRACTS

Thermal Desorption at the Arlington Blending and Packaging Superfund Site Arlington, Tennessee

Site Name:
Arlington Blending and Packaging Superfund Site

Location:
Arlington, TN

Period of Operation:
January 13 to June 4, 1996

Cleanup Authority:
CERCLA - Remedial Action
- ROD signed June 28, 1991

Purpose/Significance of Application:
Application of low temperature thermal desorption to treat pesticide-contaminated soil

Cleanup Type:
Full scale

Contaminants:
Pesticides and Metals
- Maximum concentrations during remedial investigation: chlordane (390 mg/kg surface and 120 mg/kg subsurface); endrin (70 mg/kg surface and 20 mg/kg subsurface); pentachlorophenol (130 mg/kg surface and 9.5 mg/kg) subsurface; arsenic (370 mg/kg surface)

Waste Source:
Leaks and spills of pesticides during blending and packaging operations; process wastewater discharged to drainage ditches at the site

Contacts:

Vendor:
Smith Environmental Technologies
Corporation (formerly Canonie)

EPA Remedial Project Manager:
Derek Matory
U.S. EPA Region 4
345 Courtland Street, NE
Atlanta, GA 30365
Telephone: (404) 562-8800
Fax: (404) 562-8788
E-mail: matory.derek@epa.gov

Additional Contacts:
George Harvell
Memphis Environmental Center
2603 Corporate Avenue, Suite 100
Memphis, TN 38132
Telephone: (901) 345-1788
Fax: (901) 398-4719

Paul Sadler
Senior Project Engineer
Focus Environmental, Inc.
9050 Executive Park Drive
Knoxville, TN 37923
Telephone: (423) 694-7517
E-mail: psadler@focusenv.com

Technology:
Low Temperature Thermal Desorption
- Direct-fired rotating dryer that heated the soil to between 580 and 750°F using a hot air stream
- Propane gas was used to heat the air stream, and the organic constituents in the soil were desorbed in the dryer through contact with the heated air
- Off-gas treatment included a cyclone/baghouse system; a low pressure drop Venturi air scrubber; and vapor-phase carbon adsorption
- A vacuum of 0.10 to 0.18 inches of water was maintained throughout the process train

Type/Quantity of Media Treated:
Soil - 41,431 tons
- Soils primarily silty sands with an average moisture content of 17 wt%
- pH of soil - 6.8

Regulatory Requirements/Cleanup Goals:
- Cleanup goals for organics were: chlordane (3.3 mg/kg); heptachlor (0.3 mg/kg); pentachlorophenol (0.635 mg/kg); endrin (0.608 mg/kg); heptachlor expoxide (0.2 mg/kg)
- Cleanup goal for arsenic initially established at 25 mg/kg in ROD; changed to 100 mg/kg in ESD. All treated soil with a total arsenic concentration >100 mg/kg was to be disposed of off-site. Any treated soil with total arsenic concentrations >100 mg/kg and leachable arsenic >5mg/L (determined by the toxicity characteristic leaching procedure) was required to be identified as hazardous waste and stabilized prior to disposal off-site
- Emission standards for the unit were total hydrocarbons (500 ppmv); particulates (0.08 gr/dscf); and system removal efficiency (>95%)

Thermal Desorption at the Arlington Blending and Packaging Superfund Site
Arlington, Tennessee

Results:

- A total of 84 batches of soil (41,431 tons) were treated
- All but six batches of soil met the cleanup goals for the organics on the first pass through the system
- Three batches exceeded the cleanup levels and were retreated and met the cleanup goals
- An additional three batches were slightly above the cleanup levels for total chlordane; based on the concentrations, EPA determined that the batches were not required to be retreated
- One batch of treated soil did not meet the 100 mg/kg limit for arsenic and was shipped offsite for disposal in a Subtitle C landfill; however, because the TCLP level for arsenic was below the 5 mg/L limit, solidification/stabilization prior to off-site disposal was not required
- Compliance with the emissions standards was verified during the performance test; the unit met all emissions standards during the three test runs, achieving a system removal efficiency >99.999%

Costs:

- Total project cost was $5,586,376 including $4,356,244 in costs directly associated with the thermal treatment
- Treatment costs included $4,293,893 in capital costs and $62,351 in O&M costs
- The calculated unit cost for this application was $105 per ton, based on 41,431 tons of soil treated

Description:

The Arlington Blending and Packaging Superfund site, located in Arlington, Tennessee, is a 2.3 acre site that was used for the formulation and packaging of pesticides and herbicides from 1971 to 1978. Chemicals handled at the facility included the pesticides endrin, aldrin, dieldrin, chlordane, heptachlor, lindane, methyl parathion, and thimet as well as solvents and emulsifiers used in the formulation operations. Leaks and spills of chemicals occurred during these operations and process wastewater was discharged to drainage ditches at the site. The site was placed on the National Priorities List (NPL) in July 1987. A remedial investigation (RI), begun in 1988, determined that the main areas of soil contamination at the site were located around and beneath the process buildings. The ROD, signed in 1991, specified excavation of contaminated soil and treatment on site using thermal desorption.

Smith's low temperature thermal aeration (LTTA) process was used to treat the contaminated soil at the site. The unit included a direct-fired rotating dryer that heated the soil using a hot air stream. The heated soil was discharged from the rotary dryer to an enclosed pugmill where it was quenched with water to cool and rehumidify the soil. The treated soil was then sampled, and based on the results, backfilled on site or stabilized and shipped off-site for disposal. A total of 41,431 tons of contaminated soil in 84 batches were treated during this application. All but six batches of soil met the cleanup goals for the organics on the first pass through the system. Three batches exceeded the cleanup levels and were retreated. Three additional batches slightly exceeded the cleanup goal for total chlordane. EPA determined, based on the concentrations, that the batches did not have to be retreated. Following confirmation that the cleanup goals had been met, treated soil was backfilled at the site. Only one batch of treated soil did not meet the total arsenic limit and was shipped offsite for disposal in a Subtitle C landfill. The original estimate for the soil excavation was 10,000 tons, based on the results from field-based screening using the Drexil method. Subsequent verification analyses indicated that the results from this method were not accurate. The site was recharacterized, using immunoassay sampling (results confirmed to be accurate by an off-site laboratory), and an additional 30,000 tons of soil requiring excavation were identified. The use of immunoassay sampling saved time by providing real time results (versus 5 to 6 day turnaround time for an off-site laboratory).

Thermal Desorption at Letterkenny Army Depot Superfund Site, K Areas, OU 1 Chambersburg, Franklin County, Pennsylvania

Site Name:
Letterkenny Army Depot Superfund Site K Areas, OU 1

Location:
Chambersburg, Franklin County, Pennsylvania

Period of Operation:
September 1993 to October 1994

Cleanup Authority:
CERCLA
- ROD signed June 28, 1991
- ROD modified August 2, 1991

Purpose/Significance of Application:
Thermal desorption to treat VOC-contaminated soil, including soils with high oil and grease content

Cleanup Type:
Full scale

Contaminants:
Volatile Organic Compounds and Metals
- Maximum concentrations of TCE of 30,000 mg/kg in soils in K areas
- Maximum concentrations of lead of 10,000 mg/kg in soils in K areas

Waste Source:
Disposal of waste in lagoons; leaks and spills from waste solvent drum storage area

Contacts:

Vendor:
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EPA Contact:
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Technology:
Low Temperature Thermal Desportion
- Patented I.R.V.-100 LTTD system
- 1.2 million BTU/hr system; six carbon steel treatment chambers (5 cubic yards of soil per chamber capacity)
- Each chamber equipped with 16 propane-fired infrared heaters; soil temperature of 600°F
- System operated at under a vacuum of 12 to 20 column inches of water; volumetric air flow of 500 to 1,000 cubic feet per minute per chamber
- Residence Time- 60 minutes for clay soils and 120 to 150 minutes for black stained soils
- Off-gas treatment included two cyclones, two air expansion chambers to cool the temperature of the air from about 120° F to about 90°F, and one 4,000 pound activated carbon adsorption unit

Type/Quantity of Media Treated:
Soil - 13,986 cubic yards (11,366 cubic yards of clay soil; 2,620 cubic yards of black stained soil)

Regulatory Requirements/Cleanup Goals:
- ROD specified cleanup goal for TCE in treated soil - 0.05 mg/kg
- RCRA Land Disposal Restriction treatment standards for the following VOCs - acetone, benzene, carbon tetrachloride, chlorobenzene, o-dichlorobenzene, 1,1,1-trichloroethane, 1,1,2-trichloroethane, tetrachloroethene, ethylbenzene, toluene, and total xylene) and for metals
- No goals were established for total RCRA metals
- Emissions standards for the unit included an opacity limit of < 10% for 30 minutes, total VOC emissions of < 1 pound/hour, and particulate matter of < 0.08 grains per dry standard cubic foot

Thermal Desorption at Letterkenny Army Depot Superfund Site, K Areas, OU 1 Chambersburg, Franklin County, Pennsylvania

Results:
- A total of 13,986 cubic yards of contaminated soil were treated to the cleanup goals; information on the total number of batches treated was not provided
- Soil that did not meet the cleanup goals on the first pass were retreated until the goals were met; approximately 10% of the clay soils and 14% of the black stained soils from the K-1 area required retreatment
- Treated soil that exceeded the TCLP limits for metals required to be stabilized and shipped off site for disposal; treated soils that was excavated from the top 6 feet of the K-1 area and the top 3 feet of the K-2 area were stabilized prior to off-site disposal; a total of about 4,000 cubic yards of treated soils was stabilized prior to disposal off site
- The remaining treated soil was backfilled on-site

Costs:
- Total actual project cost - $5,402,801, including $4,647,632 in actual costs for McLaren/Hart's application of thermal treatment and other project costs identified by USACE for design and project remediation ($192,827), design contract costs ($249,320), and construction contract management ($312,320)
- The unit cost for the application was $220 per cubic yard, based on 13,986 cubic yards of soil treated
- McLaren/Hart's actual costs of $4,647,632 include $2,622,470 for five modifications to the contract
- USACE subsequently paid McLaren/Hart a total of $3,905,256 for the remediation of the K area soils, as a result of a settlement agreement regarding costs of the modifications

Description:
The Letterkenny Army Depot is a 19,243-acre U.S. Army facility located in Chambersburg, Franklin County, Pennsylvania. Since 1942, the Army has used the site to overhaul, rebuild, and test missile systems; store and demilitarize ammunition; and maintain and refurbish equipment and vehicles. Operations at the facility have included degreasing, metal plating, painting and paint stripping, steam cleaning, and petroleum storage. Wastes from these operations were disposed of in landfills, trenches, pits, and surface impoundments at the site. Site investigations identified elevated levels of volatile organic compounds in soil and groundwater in the site, including three areas of soil contamination, also referred to as the K areas. K-1 was a waste disposal lagoon, K-2 was used as a transfer station, and K-3 was an area used to store drums of waste solvent. A 1992 remedial investigation identified elevated levels of TCE, polychlorinated biphenyls (PCBs), metals, and semivolatile organic compounds (SVOCs) in soils in the K areas. A Record of Decision, signed in June 1991, specified excavation of VOC-contaminated soil and on-site treatment using low temperature thermal desorption.

A low temperature thermal desorption system (LTTD), model I.R.V.- 100 designed by McLaren/Hart, was used to treat the contaminated soil from the K areas. The 1.2 million BTU/hr system, operated under vacuum, included a total of six carbon steel treatment chambers used to heat soils to temperatures up to 600°F. The unit operated from September 1993 to October 1994. A total of 13,986 cubic yards of soil were treated during this application, including 2,620 cubic yards of "black stained" soils that were encountered during the excavation of areas K-1 and K-3. The black stained soils contained heavy oils, greases, and debris and were stockpiled separately from the "clay soils" for treatment. Approximately 10% of the clay soils and 14% of the black stained soils from the K-1 area were retreated. In addition, a total of about 4,000 cubic yards of treated soils was stabilized prior to disposal. This included treated soil that was above the TCLP metals levels and from the top 6 feet of K-1 area and top 3 feet of K-2 area. The remaining treated soil was backfilled on-site. According to vendor, the presence of the black stained soils had not been anticipated at the time of the original contract. The adverse effects of these soils on the operation of the unit, from the heavy hydrocarbons in the soil, were discovered during the first demonstration test and required modification to the design and operation of the system, including expansion of the emissions controls. This resulted in increased costs and a delay in the schedule over the original plan.

Low Temperature Thermal Desorption at Longhorn Army Ammunition Plant, Karnack, Texas

Site Name:
Longhorn Army Ammunition Plant, Burning Ground No. 3

Location:
Karnack, Texas

Period of Operation:
- Proof of Performance Test - February 1997
- Full-Scale Operation - February to December 1997

Cleanup Authority:
CERCLA and State
ROD date - May 1995

Purpose/Significance of Application:
Thermal desorption to treat chlorinated solvents in the site soil and source materials

Cleanup Type:
Full scale

Contaminants:
Organic Compounds - Volatiles (Halogenated)
- Trichlororethylene (TCE) and Methylene Chloride
- Maximum concentrations in mg/kg - TCE (1,000 mg/kg) and Methylene Chloride (742 mg/kg)

Waste Source:
Open burning, incineration, evaporation, and burial of pyrotechnic and combustible solvent wastes

Contacts:

Project Management:
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Vendor:
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Radian International LLC
Longhorn Army Ammunition Plant
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Regulatory Contact:
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U.S. EPA Region 6
1445 Ross Avenue, Suite 1200
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(214) 665-6758

Diane Poteet
TNRCC
Superfund Investigation,
MC-143
12100 Park 35 Circle, Bldg. D
Austin, TX 78753

Technology:
On-Site Low Temperature Thermal Desorption (LTTD)
- Soil was fed through a vibrating screen to remove large debris
- Soil passed counter-current to hot combustion gases in one of two parallel LTTD units
- Soil was heated between 350 and 650°F
- The gas stream from each LTTD unit passed through a baghouse and then the two streams were combined
- The combined gas stream was preheated to 680°F prior to entering the catalytic oxidizer where desorbed VOCs in the gas stream were destroyed
- Hot gases exiting the oxidizer passed through a heat exchanger, multi-stage quench and packed bed scrubber
- Solids exiting the thermal desorption units and baghouses were stockpiled for compliance sampling

Type/Quantity of Media Treated:
Soil (ex situ)
- 32,293 cubic yards (51,669 tons) of soil
- Average Clay Content: 31.5 %
- Mean Particle Size: 0.032 mm
- Average Moisture Content: 17.5 %
- Bulk Soil Density: 1.6 tons per cubic yard

Low Temperature Thermal Desorption at Longhorn Army Ammunition Plant, Karnack, Texas

Regulatory Requirements/Cleanup Goals:

- If TCE or methylene chloride concentrations in the soil were below 40 mg/kg, the treatment objective was to reduce the concentrations to 2 mg/kg or lower
- If TCE or methylene chloride concentrations in the soil exceeded 40 mg/kg, the treatment objective was to reduce the concentrations by at least 95%
- Air emission requirements included control of total chemical emissions, particulate matter and 2,3,7,8-tetrachlorinated dibenzo-p-dioxin toxic equivalents in the stack gas

Results:

- Sampling of treated soil indicated that all soil cleanup goals were met
- Emissions data from the Proof of Performance test and full-scale operations indicated that all emissions standards were met

Costs:

- The total cost for this project was $4,886,978
- The total cost for treatment was $151 per cubic yard ($95 per ton) of contaminated material

Description:

Burning Ground No. 3 was operational from 1955 to 1997. The site was used for the treatment, storage, and disposal of pyrotechnic and combustible solvent wastes including open burning, incineration, evaporation and burial. Site investigations indicated the presence of high concentrations of chlorinated solvents and heavy metals in subsurface soils and shallow groundwater at the site. In addition, buried sawdust and other solvent-contaminated wastes were encountered. A ROD was signed in May 1995, specifying LTTD as the remedial technology for addressing soil contamination at the site. Site soil cleanup goals were specified in the ROD.

Mobilization and set-up of the soil treatment plant (STP) occurred in January 1997. System start-up and shake down and the Proof of Performance test were conducted in February 1997. After successfully demonstrating that the STP could meet performance requirements, the STP was put into full production. Soil/source material excavation and full-scale operation of treatment system was performed between February and December 1997. The STP consisted of a counter-current, LTTD system followed by a low-temperature, catalytic oxidation system to treat the LTTD off-gas. After confirming that treated soil met the cleanup criteria, the soil was used as general fill material for landfill caps at two sites at the LHAAP. Demobilization of the STP from the site was completed in January 1998 and site restoration was completed by June 1998.

Thermal Desorption at the Rocky Flats Environmental Technology Site, Trenches T-3 and T-4, Golden, Colorado

Site Name:
Rocky Flats Environmental Technology Site, Trenches T-3 and T-4

Location:
Golden, Colorado

Period of Operation:
June - August 1996

Cleanup Authority:
CERCLA - Removal
- Action Memorandum Date - January 18, 1996

Purpose/Significance of Application:
Application of thermal desorption to treat soils contaminated with VOCs and low levels of radiation

Cleanup Type:
Full scale

Contaminants:
Chlorinated solvents, ketones, and low level radionuclides
- The highest concentrations of VOCs in trench T-3 were TCA at 13,000 mg/kg, acetone at 5,100 mg/kg, methylene chloride at 2,400 mg/kg, and carbon tetrachloride at 700 mg/kg
- The highest concentrations of VOCs in trench T-4 were TCE at 680 mg/kg and acetone at 120 mg/kg
- Subsurface soils contaminated with low levels of radionuclides including uranium, plutonium, and tritium

Waste Source:
Burial of drums and debris in trenches on the site

Contacts:

Vendor:
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Principal Construction Manager
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Charlotte, NC 28273
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State Contact:
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CDPHE Rocky Flats Cleanup Agreement Coordinator
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DOE Contact:
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Rocky Mountain Remediation Services, LLC
Rocky Flats Environmental Technology Site
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Fax: (303) 966-8244

Technology:
Vacuum-enhanced low temperature thermal desorption
- IRV-100 system manufactured by McLaren-Hart
- 6 treatment chambers (18 feet long, 8 feet wide and 5 feet high; operating capacity of 5yd^3 per chamber)
- Each chamber equipped with 16 propane units
- Energy output of total system (infrared energy) - 1.5 MM Btu/hr
- Vacuum condition in treatment chamber - 500 mm Hg
- Air flow rate - 1,000-3,000 cfm
- Residence time - 5.25 hours
- System throughput - 1 yd^3/hour
- Soil temperature - 250°F
- Emissions controls - two dry particulate filters (in series), a condenser, and a granular activated carbon unit

Type/Quantity of Media Treated:
Soil and debris - 3,796 cubic yards
- Soils consist of sandy and clayey gravel
- Moisture content approximately 8%

Thermal Desorption at the Rocky Flats Environmental Technology Site, Trenches T-3 and T-4, Golden, Colorado

Regulatory Requirements/Cleanup Goals:

Cleanup goals specified for 12 VOCs:

- Goal of 6 mg/kg each for TCE, TCA, PCE, DCE, DCA, chloroform, carbon tetrachloride
- Goal of 10 mg/kg each for benzene, ethylbenzene, toluene
- Goal of 160 mg/kg for acetone and 30 mg/kg for methylene chloride

Results:

- A total of 58 batches (3,796 yd^3 total) of soil were treated during this application
- Of the 58 batches treated, 52 met the cleanup goals on the first pass, including 20 batches where all 12 VOCs were below the detection level
- Six batches did not meet the cleanup goals on the first pass, exceeding the level for PCE; these batches were retreated and met the cleanup goals
- Concentrations of six VOCs (TCA, DCE, DCA, carbon tetrachloride, chloroform, and ethylbenzene) were below the detection level in all 58 batches
- According to the vendor, there were no exceedances of the applicable air emissions standards

Costs:

- The total cost for this project was $1,934,203, including $1,328,600 in costs directly associated with the thermal treatment
- The calculated unit cost was \$350/yd^3 based on the treatment of the 3,796 yd^3 of contaminated soil and debris
- The original contract cost was $1,200,000, based on treating 2,200 yds^3 of contaminated soil; two change orders were issued for the remediation of additional soil volumes, changing the total amount of soil treated from 2,200 yd^3 to 3,796 yd^3, with a final project cost of $1,934,204

Description:

From 1951 to 1989, the U.S. Department of Energy (DOE) used the Rocky Flats site to process and store plutonium, manufacture components for nuclear weapons, fabricate, machine, and assemble components from metals, and store solvents used in the manufacturing processes. Hazardous and radioactive wastes were stored and disposed of at various locations at the site, including on-site trenches. Waste handling practices at the site also included recycling of hazardous materials. Trenches T-3 and T-4 were used for the disposal of sanitary sewage sludge contaminated with uranium and plutonium and miscellaneous debris, primarily flattened drums contaminated with volatile organic compounds (VOCs), uranium, and plutonium. Subsurface soils in trenches T-3 and T-4 were found to contain elevated levels of VOCs, semivolatile organic compounds, and metals, along with low-level radiological contamination. A Proposed Action Memorandum (PAM) was issued in January 1996 calling for thermal treatment of the T3/T4 soils. Prior to treatment, each load of excavated soil was screened using a Field Instrument for the Detection of Low Energy Radiation (FIDLER) to identify “potentially radiologically contaminated material”. Soil with readings above 5,000 counts per minute (cpm) was segregated and treated separately from the soil that was not considered to be potentially radioactive. A total of about 380 cubic yards of soil were identified as potentially radioactive.

The thermal desorber used at this site, an infrared radiation-heated unit manufactured by McLaren-Hart (the IRV-100 system), was a modular, batch-operated vacuum system, equipped with six treatment chambers. The system was operated under a vacuum of approximately 500 mm Hg and soil was heated to temperatures of 250°F. Thermal treatment operations were conducted from June to August, 1996. A total of 58 batches (3,796 yd^3 total) of soil were treated during this application. Fifty-two of the batches met the cleanup goals on the first pass. The six batches that did not meet the cleanup goals were retreated and met the cleanup goals. The total project cost was $1.9 million with the cost for the thermal treatment application being \$1.3 million or \$350/yd^3 (based on 3,796 yd^3 of contaminated soil and debris). According to vendor, the total project cost would likely be less for a similar application at sites where radiological engineering controls were not required.

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OTHER EX SITU SOIL TREATMENT ABSTRACTS

Slurry Reactor Biotreatment of Explosives-Contaminated Soils at Joliet Army Ammunition Plant, Joliet, Illinois

Site Name:
Joliet Army Ammunition Plant

Location:
Joliet, Illinois

Period of Operation:
July 1994 to August 1995

Cleanup Authority:
CERCLA
- Final ROD scheduled for June 2001

Purpose/Significance of Application:
Use of bioslurry technology for treatment on explosives wastes

Cleanup Type:
Field demonstration

Contaminants:
Explosives
- Excavated soils had concentrations of TNT - 1,000 - 6,226 mg/kg; DNT - ND - 360 mg/kg; TNB - 48 - 360 mg/kg; RDX - ND - 310 mg/kg; and HMX - ND - 215 mg/kg

Waste Source:
Process water from munitions washout

Contacts:

Technical Contacts:
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Technology:
In Situ Bioremediation
- Field bioslurry system included a soil screening operation, four 420-gallon bioslurry reactor tanks (variable speed drive mixer with double impeller); two slurry dewatering beds; and tanks for water storage
- Bioslurry demonstration was performed in the reactors (350-380 gals/reactor), with addition of molasses, pH adjustment (to >6), and aerobic-anoxic operating cycles
- Four reactors were operated: (1) a control with no molasses; (2) a 20% weekly replacement; (3) a 10% weekly replacement; and (4) a 5% daily replacement
- All reactors were operated with a 10-16% W/W soil slurry in a sequencing batch mode
- Soil was screened to 40 mesh (0.0165 inch) prior to placement in the reactors

Type/Quantity of Media Treated:
Soil

Regulatory Requirements/Cleanup Goals:
- Determine effectiveness and cost of bioslurry systems for degrading explosives in soil
- Evaluate a field-scale system for mechanical integrity and ability to enrich a microbial consortium, and to analyze system performance over an extended operating period
- A target goal of 20 mg/kg for TNT was used for the demonstration, since a cleanup goal had not yet been established

Slurry Reactor Biotreatment of Explosives-Contaminated Soils at Joliet Army Ammunition Plant, Joliet, Illinois

Results:
- Removed more than 99% of explosives from the soil
- The 20% weekly replacement reactor (soil retention time of 5 weeks), when operated at >25ºC, degraded TNT to <50 mg/kg and DNT to <100 mg/kg, and RDX and TNB to <10 mg/kg; the report does not indicate if this reactor met the target goal for TNT
- The 10% weekly replacement reactor (soil retention time of 10 weeks), when operated at >25ºC, degraded TNT to <20 mg/kg and DNT to <10 mg/kg, and RDX and TNB to <10 mg/kg
- The 5% daily replacement reactor (soil retention time of 5 weeks) had performance similar to that of the 20% weekly replacement reactor, and removed TNT to <20 mg/kg
- The control reactor (no molasses addition) showed no explosives removed from the soil

Costs:
- Projected costs for full-scale implementation of the slurry-phase biotreatment system was \$290-350/yd^3

Description:
Joliet Army Ammunition Plant was constructed in Will County, Illinois, approximately 17 miles south of Joliet, in the early 1940's. JAAP contains two major functional areas - a manufacturing area for production of constituent chemicals and explosive materials, covering 14 square miles, and a load-assemble-package (LAP) area for munitions filling and assembly lines, storage magazines, and demilitarization, covering 27 square miles. In April 1989, the LAP area was added to the NPL. Soil for a field demonstration of bioslurry technology was obtained from Group 61, Site L1 of the LAP Area, a ridge-and-furrow area that received pink water from washout of munitions.

The field demonstration showed that bioslurry technology could reduce concentrations of TNT and other explosives in soil. The important process parameters are the need for an organic co-substrate (molasses), operation of the reactors in an aerobic-anoxic sequence, and temperature. In warmer temperatures (>25ºC), operation of the system at ≥20% weekly replacement will achieve removal of explosives. Colder temperatures did not destroy the microbial activity, but did slow the metabolic rate. In particular, degradation of TNT continued with the accumulation of DNT. The reactors were operated successfully at lower replacement rates (≤10% weekly) in colder weather. The treated soil (bioslurry) can be applied directly to land and will not affect plant growth.

Joint Small Arms Range Remediation (Physical Separation and Acid Leaching) at Fort Polk Range 5, Leesville, Louisiana

Site Name:
Fort Polk Range 5

Location:
Leesville, Louisiana

Period of Operation:
August - December, 1996

Cleanup Authority:
RCRA

Purpose/Significance of Application:
Demonstration of physical separation and acid leaching to treat metals in soil

Cleanup Type:
Field demonstration

Contaminants:
Heavy Metals - Lead
- Stockpiled untreated soil had a lead assay of 0.5%

Waste Source:
Small arms testing

Contacts:

Vendor Contacts:
Acetic Acid Leaching:
Thomas Leggiere
ContracCon Northwest Inc

Hydrochloric Acid Leaching:
Craig Jones
Brice Environmental Corporation

Army Contacts:
Richard O'Donell
Lisa Miller
Army Environmental Center

Technology:
Physical separation and acid leaching
- Demonstration included two vendors - one used physical separation and acetic acid (weak acid) leaching; the other used physical separation and hydrochloric acid (strong acid) leaching
- Physical separation for both vendors included screening to remove oversize debris, including bullets and bullet fragments; hydrodynamic separation; density separation; froth flotation; and magnetic separation
- Following separation, the soil was mixed with the acid in a tank; for the acetic acid leaching, three tanks were used in series; for the hydrochloric acid leaching, one mix tank was used
- The treated soil slurry was separated from the leachate and dewatered (filter press); leachate was regenerated (preciptiation)
- Average processing rate - 2.8 tons/hr (acetic acid) and 6.3 tons/hr (hydrochloric acid)

Type/Quantity of Media Treated:
Soil
- Acetic acid leaching process - 263 tons
- Hydrochloric acid leaching process - 835 tons

Regulatory Requirements/Cleanup Goals:
- TCLP for lead of 5 ug/L
- Total metals concentration for lead, copper, zinc, and antimony - 1,000 mg/kg each for acetic acid leaching and 500 mg/kg each for hydrochloric acid leaching

Results:
- Soil from physical separation alone was tested for TCLP lead; did not meet cleanup criteria
- Acetic Acid Leaching:
  - Initially, approximately 93% total lead, 93% total copper, 77% total zinc, and 70% total antimony removed
  - During the demonstration, both total and leachable lead levels in treated soil rose due to buildup of lead in regenerated leachate as a result of inadequate precipitation
  - Total lead was reduced from 2,828 mg/kg in untreated soil to 122-1,443 mg/kg in processed soil; data on TCLP lead levels was not provided
- Hydrochloric Acid Leaching:
  - Met both total and TCLP lead targets throughout demonstration
  - Removed 96% total lead, 97% total copper, 89% total zinc, and 60% total antimony
  - Total lead was reduced from 4,117 mg/kg in untreated soil to 165 mg/kg in treated soil
  - Average TCLP lead level in treated soil was 2 mg/L

Joint Small Arms Range Remediation (Physical Separation and Acid Leaching) at Fort Polk Range 5, Leesville, Louisiana

Costs:

- Costs from the acid leaching demonstration were not analyzed because of the operational difficulties experienced with leachate regeneration
- Costs for physical separation and hydrochloric acid leaching demonstration were $1,400/ton for the 835 tons of soil processed
- Projected full-scale costs for physical separation and hydrochloric acid leaching are $170/ton based on 10,000 tons of soil

Description:

A demonstration of physical separation and acid leaching of soil from a small arms testing range at Fort Polk was conducted from August to December, 1996. Two types of acid leaching were demonstrated - one using acetic acid to demonstrate a weak acid and one using hydrochloric acid to demonstrate a strong acid. Soil containing heavy metals was excavated from the small arms range and stockpiled for the demonstration. The soil was sent through physical separation followed by acid leaching. The treated soil was separated from the leachate, and dewatered; the leachate was regenerated and reused in the process.

Results showed that treating soil using physical separation alone did not meet the cleanup goals. While the acetic acid leaching initially removed metals, operational problems with the regeneration of the leachate resulted in increasing levels of lead in the treated soil. The hydrochloric acid leaching process met the cleanup goals for all metals throughout the demonstration. Projected full-scale costs for physical separation and hydrochloric acid leaching are $170/ton based on 10,000 tons of soil treated.

Thermo NUtech's Segmented Gate System at Los Alamos National Laboratory Technical Area 33, Los Alamos, New Mexico

Site Name:
Los Alamos National Laboratory Technical Area 33
(Report also addresses testing from Site TA-15)

Location:
Los Alamos, New Mexico

Period of Operation:
April 28 – May 19, 1999
(soil processing on 15 days)

Cleanup Authority:
Voluntary Corrective Action

Purpose/Significance of Application:
Use of a gate system to reduce volume of radioactive-contaminated soil requiring off-site disposal

Cleanup Type:
Full scale

Contaminants:
Natural Uranium (NU) and Depleted Uranium (DU)
- Concentrations reported as high as 431.46 pCi/g

Waste Source:
Nuclear weapon production operations

Contacts:

Vendor:
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Thermo NUtech
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(505) 254-0935 ext. 209

Management Support:
Ray Patteson, Sandia National Laboratories, (505) 884-1904
John McCann, Los Alamos National Laboratory, (505) 665-1091

Technology:
Segmented Gate System (SGS)
- SGS is a combination of conveyor systems, radiation detectors (primarily gamma radiation), and computer control used to segregate waste by contamination level
- Detectors monitored radioactivity content of soil traveling on belt and computer opened specified gates to separate portions of soil based on radioactivity criteria
- Contaminated soil on conveyor belt was diverted by segmented gates into stockpiles
- Operating parameters included a belt speed of 30 ft/min, belt length of 16 - 18 ft, soil layer thickness of 2 in by width of 30.75 in, and soil density of 1.02 g/cm^3
- Total soil processing time was 91.1 hrs; average daily operational time was 6.48 hrs
- Oversize debris and rock pre-screened

Type/Quantity of Media Treated:
Soil and Debris
- 2,526 yds^3 of soil were processed
- Soil moisture content estimated as 12-15%

Regulatory Requirements/Cleanup Goals:
- Reduce the volume of contaminated soil by separating soil that was above the specified criteria and that would require off-site storage and disposal, from soil that was below the criteria
- The sorting criterion was 50 pCi/g

Results:
- Overall volume reduction of contaminated soil was 91.64%; approximately 350 yds^3 of above-criteria soil required off-site disposal
- Average activities for soil from Sites C33-003, C33-010, and C33-007b were: above-criteria 318, 431.46, and 165.89 pCi/g, respectively, and below-criteria soil: 3.2, 44.8, and 9.88 pCi/g

Costs:
- Actual cost for SGS was $275,745, including $6,600 for pre-deployment activities, $46,000 for mobilization, $185,445 for processing, $35,000 for demobilization, and $2,700 for final report
- Additional costs incurred by LANL were $543,400, including for staff, prime contractor, G&A, and soil disposal
- Overall unit cost of SGS was $109/yd^3 of soil processed

Thermo NUtech's Segmented Gate System at Los Alamos National Laboratory Technical Area 33, Los Alamos, New Mexico

Description:
Los Alamos National Laboratory (LANL) is a 43-square mile multi-disciplinary research facility owned by the U.S. DOE and located in north-central New Mexico. Technical Area 33 (TA-33), located in the eastern portion of LANL, is an active testing area. TA-33 was used to test initiators (components of nuclear weapons) from 1947 to the 1950's. This report focused on remediation of uranium-contaminated soil and debris from Potential Release Sites (PRSs) 33-007(b), 33-010(c), and C33-003 in TA-33. Historical records indicate that natural uranium (NU) and depleted uranium (DU) are present at these sites.

A Segmented Gate System (SGS) was used to reduce the volume of radioactive-contaminated soil that required off-site disposal. SGS is a combination of conveyor systems, radiation detectors, and computer control, where contaminated soil on a conveyor belt is diverted by segmented gates into stockpiles by contamination level. Detectors monitor the radioactivity content of the soil traveling on the belt and a computer opens specified gates to separate portions of the soil based on radioactivity criteria. At this site, the overall volume reduction was measured as 91.64%. The actual cost for the application was \$275,745, including \$185,445 for processing. This corresponded to an overall unit cost of \$109/yd^3 based on 2,526 yd^3. During the demonstration, delays were caused by operational failures from hydraulic systems.

Thermo NUtech's Segmented Gate System at Pantex Plant, Firing Site 5, Amarillo, Texas

Site Name:
Pantex Plant, Firing Site 5

Location:
Amarillo, Texas

Period of Operation:
March 27 - May 1, 1998
(soil processing from April 17 - April 19, 1999)

Cleanup Authority:
RCRA Corrective Action

Purpose/Significance of Application:
Use of a gate system to reduce volume of radioactive-contaminated soil requiring off-site disposal

Cleanup Type:
Full scale

Contaminants:
Depleted Uranium (DU)
- Concentrations reported as high as 567 pCi/g

Waste Source:
Firing range for test shots of depleted uranium and explosives

Contacts:

Site Contact:
Martin Amos, Battelle Pantex
(806) 477-6458

Vendor:
Scott Rogers, Thermo Nutech
(423) 481-0683

Management Support:
Tom Burford, Sandia National Laboratories,
(505) 845-9893

Technology:
Segmented Gate System (SGS)
- SGS is a combination of conveyor systems, radiation detectors (primarily gamma radiation), and computer control used to segregate waste by contamination level
- Detectors monitored radioactivity content of soil traveling on belt and computer opened specified gates to separate portions of soil based on radioactivity criteria
- Contaminated soil on conveyor belt was diverted by segmented gates into stockpiles
- Operating parameters included a belt speed of 30 ft/min, belt length of 16 - 18 ft, soil layer thickness of 2 in by width of 30.75 in, and soil density of 1.0 g/cm^3
- Average daily operational time was 2.67 hrs
- Oversize debris and rock pre-screened

Type/Quantity of Media Treated:
Soil and Debris
- 294 yds^3 of soil were processed
- Soil moisture content estimated as 17%

Regulatory Requirements/Cleanup Goals:
- Reduce the volume of contaminated soil by separating soil that was above the specified criteria and that would require off-site storage and disposal, from soil that was below the criteria
- The sorting criterion was 50 pCi/g

Results:
- Overall volume reduction of contaminated soil was 38.5%; approximately 180.8 yds^3 of above-criteria soil required off-site disposal
- Average activities ranged from 125 - 213 pCi/g for above-criteria soil and 20 - 54 pCi/g for below-criteria soil

Costs:
- Actual cost for SGS was $203,887, including $18,768 for regulatory and compliance issues, $103,015 for mobilization, $32,594 for soil processing, and $49,510 for demobilization
- Additional costs incurred by LANL were for site preparation, excavation, oversight labor, health physics support, sample analysis, and waste disposal (specific cost data not provided)
- Unit cost of SGS was $111/yd^3 based on 294 yd^3 of soil

Thermo NUtech's Segmented Gate System at Pantex Plant, Firing Site 5, Amarillo, Texas

Description:
Firing Site 5 (FS-5) is within the boundaries of the Pantex Plant, located northeast of Amarillo, Texas. The site was used to conduct test shots of combined explosives and depleted uranium. The firing site was surrounded on three sides by an earthen berm 10 ft high and 33 ft thick at the base. Soil at the site was contaminated with depleted uranium (DU).

A Segmented Gate System (SGS) was used to reduce the volume of radioactive-contaminated soil that required off-site disposal. SGS is a combination of conveyor systems, radiation detectors, and computer control, where contaminated soil on a conveyor belt is diverted by segmented gates into stockpiles based on contamination level. Detectors monitor the radioactivity content of the soil traveling on the belt and a computer opens specified gates to separate portions of the soil based on radioactivity criteria. At this site, the overall volume reduction for the first 294 yds^3 of soil treated was measured as 38.5%, and the results were determined to be unsatisfactory; processing was terminated at this time. The actual cost for the application was \$203,887, including \$32,594 for soil processing. This corresponded to a unit cost of \$111/yd^3 for soil processing. Lessons learned included problems with using a hand survey method for classifying soil, which resulted in misclassifying soil as above the SGS criterion, and the method used each day to cover and uncover the piles.

Thermo NUtech's Segmented Gate System at Sandia National Laboratories, ER Site 16, Albuquerque, New Mexico

Site Name:
Sandia National Laboratories, ER Site 16

Location:
Albuquerque, New Mexico

Period of Operation:
February - March 1998
(soil processing from February 27 – March 5, 1998)

Cleanup Authority:
RCRA Corrective Action
- Part B permit issued 8/93

Regulatory Authority:
New Mexico Environment Department

Purpose/Significance of Application:
Use of a gate system to reduce volume of radioactive-contaminated soil requiring off-site disposal

Cleanup Type:
Full scale

Contaminants:
Depleted Uranium (DU)
- Concentrations reported as high as 4,100 pCi/g

Waste Source:
Dump Site

Contacts:

Site Contact:
Tom Burford
Sandia Corporation
DOE/AL
(505) 845-9893

Vendor:
Scott Rogers
Thermo NUtech
A ThermoRetec Company
4501 Indian School Road NE, Suite G105
Albuquerque, NM 87110
(505) 424-3072

Technical Support:
Sue Collins
Sandia National Laboratories
(505) 284-2546

Technology:
Segmented Gate System (SGS)
- SGS is a combination of conveyor systems, radiation detectors (primarily gamma radiation), and computer control
- Contaminated soil on conveyor belt was diverted by segmented gates into stockpiles
- Detectors monitored radioactivity content of soil traveling on belt and computer opened specified gates to separate portions of soil based on radioactivity criteria
- Operating parameters included a belt speed of 30 ft/min, belt length of 16 - 18 ft, soil layer thickness of 2 in by width of 30.75 in, and soil density of 1.0 g/cm^3
- Average daily processing time was 4.7 hrs, less than the target of 7 hrs
- Oversize debris and rock pre-screened using a field grizzly (vertical bar grate) and hammermill

Type/Quantity of Media Treated:
Soil
- 661.8 yds^3 of soil were processed
- Soil identified as silty sands, containing 35-45% silt and clay; moisture content estimated as 10%

Regulatory Requirements/Cleanup Goals:
- Reduce the volume of contaminated soil by separating soil that was above the specified criteria and that would require off-site storage and disposal, from soil that was below the criteria
- The sorting criterion was 54 pCi/g

Results:
- Overall volume reduction of contaminated soil was 99.9%; 358 kg of above-criteria soil required off-site disposal
- After first pass, average activity of above-criteria soil was 406.5 pCi/g and below-criteria soil 4.2 pCi/g

Costs:
- Actual cost was $164,109, including $59,326 for mobilization, $57,770 for operations, and $47,013 for demobilization
- Overall unit cost was $236/yd^3 of soil processed, reflecting the relatively small amount of soil processed
- Additional activities included site preparation, operation of crane, excavation, oversight labor, health physics support, water supply, sample analysis, and waste disposal

Thermo NUtech's Segmented Gate System at Sandia National Laboratories, ER Site 16, Albuquerque, New Mexico

Description:
Sandia National Laboratories' Environmental Restoration (ER) Site 16 is located northeast of the Technical Area III/V complex, within Kirtland Air Force Base. The site covers 25 acres and was an open dumping ground for concrete and other rubble. The concrete and rubble was presumed to be the source on contamination. Approximately 1/3 acre was excavated for the project from the side and bottom of an arroyo, after the removal of larger debris.

A Segmented Gate System (SGS) was used to reduce the volume of radioactive-contaminated soil that required off-site disposal. SGS is a combination of conveyor systems, radiation detectors, and computer control, where contaminated soil on a conveyor belt is diverted by segmented gates into stockpiles. Detectors monitor the radioactivity content of the soil traveling on the belt and a computer opens specified gates to separate portions of the soil based on radioactivity criteria. At this site, the overall volume reduction was measured as 99.9%. The actual cost for the application was \$164,109, including \$59,326 for mobilization, \$57,700 for operations, and \$47,013 for demobilization. This corresponded to an overall unit cost of \$236/yd^3. Lessons learned included impacts from startup requirements, jams in the screen/hammermill caused by larger rocks, and soil buildup in the gas chutes.

Thermo NUtech's Segmented Gate System at Sandia National Laboratories, ER Site 228A, Albuquerque, New Mexico

Site Name:
Sandia National Laboratories, ER Site 228A

Location:
Albuquerque, New Mexico

Period of Operation:
July - November 1998
(soil processing from November 6-17, 1998)

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Use of a gate system to reduce volume of radioactive-contaminated soil requiring off-site disposal

Cleanup Type:
Full scale

Contaminants:
Depleted Uranium (DU)
- Concentration not provided

Waste Source:
Burial pits

Contacts:

Site Contact:
Sandia Corporation
DOE/AL

Vendor:
Thermo NUtech
A ThermoRetec Company
4501 Indian School Road NE, Suite G105
Albuquerque, NM 87110

Technical Support:
Sue Collins
Sandia National Laboratories
(505) 284-2546

Technology:
Segmented Gate System (SGS)
- SGS is a combination of conveyor systems, radiation detectors (primarily gamma radiation), and computer control
- Contaminated soil on conveyor belt was diverted by segmented gates into stockpiles
- Detectors monitored radioactivity content of soil traveling on belt and computer opened specified gates to separate portions of soil based on radioactivity criteria
- Operating parameters included a belt speed of 30 ft/min, belt length of 16 - 18 ft, soil layer thickness of 2 in by width of 30.75 in, and soil density of 1.29 g/cm^3
- Average daily processing time was 4.47 hrs, less than the target of 7 hrs
- Oversize debris and rock pre-screened using a field grizzly (vertical bar grate) and hammermill

Type/Quantity of Media Treated:
Soil
- 1,352 yds^3 of soil were processed
- Extended 0.4 acres at a depth of 2 ft
- Soil identified as sandy, moisture content estimated as 10%

Regulatory Requirements/Cleanup Goals:
- Reduce the volume of contaminated soil by separating soil that was above the specified criteria and that would require off-site storage and disposal, from soil that was below the criteria
- The sorting criterion was 27 pCi/g

Results:
- Overall volume reduction was measured as 99.56%; 21 55-gallons drums of above-criteria soil required off-site disposal
- Average activity of above-criteria soil was 223 pCi/g and below-criteria soil 14.77 pCi/g
- 5.2 yds^3 of soil from Burn Site showed volume reduction of 99.4%

Costs:
- Actual cost was $220,040, including $29,000 for excavation and pre-screening, $41,300 for mobilization, $117,000 for operations, and $32,340 for demobilization
- Overall unit cost was $154/yd^3, reflecting the relatively small quantity of soil processed
- Project contracted as a lump sum fixed price; did not include excavation, oversight labor, health physics support, water supply, fuel services, generator support, sample analysis, and waste disposal

Thermo NUtech's Segmented Gate System at Sandia National Laboratories, ER Site 228A, Albuquerque, New Mexico

Description:
Environmental Restoration (ER) Site 228A, the Centrifuge Dump Area and Tijeras Arroyo Operative Unit-ADS 1309, is located 500 ft east of Technical Area II, within Kirtland Air Force Base. In July 1997, heavy rains eroded a portion of a depleted uranium burial from the Tijeras Arroyo rim. Depleted uranium mixed with soil and debris washed down the slope.

A Segmented Gate System (SGS) was used to reduce the volume of radioactive-contaminated soil that required off-site disposal. SGS is a combination of conveyor systems, radiation detectors, and computer control, where contaminated soil on a conveyor belt is diverted by segmented gates into stockpiles. Detectors monitor the radioactivity content of the soil traveling on the belt and a computer opens specified gates to separate portions of the soil based on radioactivity criteria. At this site, the overall volume reduction was measured as 99.56%. The actual cost for the application was \$220,040, including \$29,000 for excavation and pre-screening, \$41,300 for mobilization, \$117,000 for operations, and \$32,340 for demobilization. This corresponded to an overall unit cost of \$154/yd^3. Lessons learned included impacts from weather delays and equipment concerns, and difficulties with rocks that were 3 inches in diameter.

Thermo NUtech's Segmented Gate System at Tonapah Test Range, Clean Slate 2, Tonapah, Nevada

Site Name: Tonapah Test Range, Clean Slate 2	**Location:** Tonapah, Nevada
Period of Operation: May 4 – June 12, 1998 (soil processing from May 18 – June 3, 1999)	**Cleanup Authority:** RCRA Corrective Action
Purpose/Significance of Application: Use of a gate system to reduce volume of radioactive-contaminated soil requiring off-site disposal	**Cleanup Type:** Field demonstration
Contaminants: Plutonium - Concentrations reported as high as 1,100 pCi/g	**Waste Source:** Weapons test range

Contacts: **Vendor:** Scott Rogers, Thermo Nutech, (423) 481-0683 **Management Support:** Tom Burford, Sandia National Laboratories, (505) 845-9893 **Technical Contact:** Mike Hightower, Sandia National Laboratories, (505) 844-5499	**Technology:** Segmented Gate System (SGS) • SGS is a combination of conveyor systems, radiation detectors (primarily gamma radiation), and computer control used to segregate waste by contamination levels • Detectors monitored radioactivity content of soil traveling on belt and computer opened specified gates to separate portions of soil based on radioactivity criteria • Contaminated soil on conveyor belt was diverted by segmented gates into stockpiles, based on the criteria • Operating parameters included a belt speed of 30 ft/min, belt length of 16 - 18 ft, soil layer thickness of 1 - 2 in by width of 30.75 in, and soil density of 1.0 g/cm^3 • Oversize debris and rock were pre-screened
	Type/Quantity of Media Treated: Soil and Debris • 333 yds^3 of soil were processed • Soil was primarily sand and silt with some gravel and cobbles; soil type and moisture content optimal for SGS operation

Regulatory Requirements/Cleanup Goals:

- Reduce the volume of contaminated soil by separating soil that was above the specified criteria and that would require off-site storage and disposal, from soil that was below the criteria
- The sorting criterion was 50 - 1,500 pCi/g; demonstration results were to be used to define optimum operating parameters

Results:

- 79 runs were conducted, each characterized by different soil activity levels, operating parameters, and end points (sorting criterion)
- Results showed that optimum separation criteria for soils with <400 pCi/g was about 300 pCi/g, resulting in a volume reduction of 60% and an average clean soil activity of 160 pCi/g
- Soils between 400 - 800 pCi/g did not appear to have an optimum separation criterion, and had a volume reduction of 30 - 40% and an average clean soil activity of 250 pCi/g
- Soils >800 pCi/g did not appear to have an optimum separation criterion, and had a volume reduction of 30% and an average clean soil activity of 500 pCi/g; this clean soil activity was too high and suggested that processing soil with >800 pCi/g would probably not be appropriate

Costs:

- Actual cost for SGS was $138,126, including $8,203 for regulatory and compliance issues, $29,614 for mobilization, $78,545 for physical treatment, and $21,764 for demobilization

Thermo NUtech's Segmented Gate System at Tonapah Test Range, Clean Slate 2, Tonapah, Nevada

Description:
Tonapah Test Range is a DOE and DoD weapons testing range. The Clean Slate-2 soil remediation site of the range is in the northwest portion of Nellis Air Force Base. In 1963, a series of four nuclear weapons, component, and explosive vulnerability destruction experiments, known as Operation Roller Coaster, were conducted at the range. These experiments left varying levels of finely dispersed plutonium at the site. Approximately 32,000 yds^3 of soil in Clean Site-2 are contaminated, with the site still being characterized.

A Segmented Gate System (SGS) was used to reduce the volume of radioactive-contaminated soil that required off-site disposal. SGS is a combination of conveyor systems, radiation detectors, and computer control, where contaminated soil on a conveyor belt is diverted by segmented gates into stockpiles based on contamination levels. Detectors monitor the radioactivity content of the soil traveling on the belt and a computer opens specified gates to separate portions of the soil based on radioactivity criteria. At this site, 79 periods of operation (runs) were conducted, each characterized by different soil activity levels, operating parameters, and end points (sorting criterion) ranging from 50 to 1,500 pCi/g. Results showed that optimum separation criteria for soils with <400 pCi/g was about 300 pCi/g, resulting in a volume reduction of 60% and an average clean soil activity of 160 pCi/g. Soils >400 pCi/g did not appear to have an optimum separation criterion. Results suggested that processing soil with >800 pCi/g would probably not be appropriate for the SGS. Actual cost for SGS was $138,126, including $78,545 for soil processing. Results from these tests were used to develop potential treatment scenarios for the SGS at Clean Slate-2. Lessons learned covered topics such as the need for accurate site characterization data and the benefits of selective excavation of hot spots.

Chemical Extraction for Uranium Contaminated Soil at the RMI Titanium Company Extrusion Plant, Ashtabula, Ohio

Site Name:
RMI Titanium Company Extrusion Plant

Location:
Ashtabula, Ohio

Period of Operation:
January 7, 1997 - February 14, 1997

Cleanup Authority:
NRC

Purpose/Significance of Application:
Demonstration of chemical leaching process for treatment of uranium-contaminated soil

Cleanup Type:
Field demonstration

Contaminants:
Radionuclides - Uranium
- Most uranium present as U^{+236}
- Uranium levels in feed soil were 74 - 146 pCi/g

Waste Source:
Particulates from uranium extrusion operations

Contacts:

DOE Contacts:
Ward Best, DOE Ashtabula Area Office, (216) 993-1944
Jeff Kulpa, RMI Environmental Services, (216) 993-2804
Erik Groenendijk, ART pilot project manager, (813) 264-3529

Mike Hightower
Sandia National Laboratories
Telephone: (505) 844-5499
Fax: (505) 844-0116
E-mail: mmhight@sandia.gov

EPA Contact:
Brian Nickel
Ohio EPA
401 East Fifth Street
Dayton, OH 45402-2911
Telephone: (513) 285-6357
Fax: (513) 285-6249

Technology:
Chemical Extraction
- Process involves application of heated bicarbonate solution to soil in a rotary reactor, liquid/soils separation, dewatering, and ion exchange to remove uranium from liquid
- Solution was 0.2 M $NaHCO_3$ at a 115°F and retention time of 1.5 hrs; reactor was a 5 yd^3 cement mixer
- Processed 1 to 2 tons of soil/batch, using a 30% solids slurry

Type/Quantity of Media Treated:
Soil
- 64 tons (38 batches)
- high clay content silt loams and clay loams; low organic material

Regulatory Requirements/Cleanup Goals:
- Evaluate process performance, such as ability to meet a 30 pCi/g free release standard and achieve a significant volume reduction of the waste

Results:
- Treated soil from two areas of the plant had 12-14 pCi/g of uranium, with removal efficiencies of 87-91%
- Treated soil from another area of the plant had 27-47 pCi/g; the higher concentrations was attributed to high feed concentrations from a hot spot with 587 pCi/g
- Volume reduction was 95%; less than 5% residual waste required off-site disposal
- Average feed concentration to ion exchange was 16 ppm and output 1.7 ppm, resulting in a 91% removal efficiency

Costs:
- The total cost for the pilot plant was $638,670, including mobilization and preparatory work; monitoring, sampling, testing, and analysis; chemical treatment; decontamination and decommissioning; disposal commercial; demobilization; and data compilation and report writing
- The report authors indicate that a linear relationship does not exist between pilot plant and full-scale costs
- Full-scale costs were estimated to range from $250-350 per ton of soil treated

Chemical Extraction for Uranium Contaminated Soil at the RMI Titanium Company Extrusion Plant, Ashtabula, Ohio

Description:
From 1962 to 1988, the RMI Titanium Company (RMI) performed uranium extrusions operations for the U.S. DOE at its plant in Ashtabula, Ohio. The uranium metal processed at the site included deleted and slightly enriched material that was used in nuclear and non-nuclear weapons. During the early years of extrusion and machining, particulate uranium was generated and discharged from roof vents and stacks and settled on surrounding soils. A test of a carbonate extraction process was conducted to leach uranium from contaminated soils.

Thirty-eight batches of 1-2 tons/batch were treated in a pilot-scale test of a chemical extraction process, through DOE's ITRD program. Treated soil had an overall removal efficiency of approximately 82% with a volume reduction of 95%; less than 5% of residual waste required off-site disposal. Difficulties with meeting the cleanup goal were identified only when treating soil from a hot spot. The total cost for the pilot plant was $638,670, and full-scale costs were estimated as $250-350/ton.

Transportable Vitrification System at Oak Ridge National Laboratory, Oak Ridge, Tennessee

Site Name:
Oak Ridge National Laboratory (ORNL)

Location:
Oak Ridge, TN

Period of Operation:
October 1997

Cleanup Authority:
RCRA and NRC

Purpose/Significance of Application:
Demonstration of a transportable vitrification system to treat low-level mixed waste sludges

Cleanup Type:
Field demonstration

Contaminants:
Metals and Radionuclides

Waste Source:
Mixed low-level waste sludges from DOE operations - included pond sludge and sludge from a neutralization facility

Contacts:

Principal Investigator:
Frank Van Ryn
Bechtel Jacobs Company
ORNL
P.O. Box 2003
Oak Ridge, TN 37831
Telephone: 423-574-1907
Fax: 423-574-9786
E-mail: xs2@ornl.gov

DOE Technical Program Manager:
Dave Hutchins
Environmental Technology Group, EM-93
U.S. DOE, Oak Ridge Operations Office
P.O. Box 2001
Oak Ridge, TN 37831
Telephone: 423-241-6420
Fax: 423-576-5333
E-mail: hutchinsda@oro.doe.gov

Technology:
Vitrification
Transportable Vitrification System (TVS):
- Waste and Additives and Materials Processing Module - 240-gal melter feed blend tank equipped with a load cell and agitator, centrifugal pump, feed tank, melter module, and emission control module
- Melter Module - joule-heated glass melter equipped with molybdenum rod electrodes and lined with heavy flux contact refractory
- Melter capacity - up to 300 lb/hr; operating temperature - 1,150 to 1,400°C; heated with a 500,000-BTU/hr propane burner
- Melter equipped with a drain bay chamber to remove waste glass and salt tap side chamber to remove corrosive salts
- Waste glass poured from drain bay chamber into 8-cubic foot stainless steel containers
- Emission Control Module included quench tower, packed bed cooler, variable throat venturi, mist eliminator, reheater, and high-efficiency particulate air filters
- Control and Services Module - used to control and monitor equipment operation

Type/Quantity of Media Treated:
Sludge
- Pond sludge and mixtures of pond and neutralization sludge - 16,000 lbs

Regulatory Requirements/Cleanup Goals:
- RCRA Land Disposal Restriction (LDR) standards and NRC guidelines
- Air emissions limits were specified in a State of Tennessee air permit

Results:

- The waste form produced by the TVS met the RCRA LDR standards and NRC guidelines, was stable and durable, and represented a 60% volume reduction of the waste
- The TVS system operated within the required emissions limits
- The melting rate decreased during the demonstration, resulting in lower average throughput rate (450 kg/day versus expected 900 kg/day); attributed to high iron content of waste which decreased heat transfer characteristics of glass material

Costs:

- Projected costs for a full-scale system include:
    - Capital costs, including all equipment - $5 million
    - Operating costs - $10 to $44/kg of waste, assuming analytical expenses similar to those incurred for the demonstration; assuming less extensive analytical requirements for normal operations, operating costs were estimated at $7 to $17/kg of waste

Description:

In October 1997, following completion of process development and testing, demonstration of the TVS was conducted at ORNL, using actual low-level mixed waste containing metals. The waste used for the demonstration was B&C pond sludge and a mix of B&C pond sludge and sludge from a neutralization facility. The objectives of the demonstration included meeting the RCRA LDR standards and NRC guidelines for the glass waste form, meeting the air emissions limits for the operation of the TVS, and collecting operating and performance data for the process for use in scale-up.

The results of the demonstration showed that the TVS was capable of treating low-level mixed waste sludges to the RCRA LDR levels and the NRC guidelines, and of operating within the required air emission standards. The waste form produced by the TVS was highly durable with long-term integrity, and significant reductions in waste volumes were achieved. For different waste compositions from those tested, additional process development would be required to determine the process controls and scale-up methods needed to achieve optimal glass waste forms, consistent melter operation, and to avoid adverse melter conditions. Treatability studies are recommended for any waste stream to be treated using TVS.

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PUMP AND TREAT ABSTRACTS

Groundwater Extraction and Treatment at the Logistics Center Operable Unit, Fort Lewis, Washington

Site Name:
Fort Lewis Logistics Center Operable Unit

Location:
Fort Lewis, Washington

Period of Operation:
August 1995 - ongoing

Cleanup Authority:
CERCLA Remedial Action
Record of Decision (ROD) signed on September 25, 1990

Purpose/Significance of Application:
Use of two groundwater extraction systems to remove VOCs and treat using air stripping.

Cleanup Type:
Full scale

Contaminants:
Organic Compounds, Halogenated (Chlorinated Solvents) - TCE and DCE
Maximum TCE concentration in groundwater is greater than 100,000 mg/L.

Waste Source:
Disposal of waste solvents in surface trenches, including disposal of free liquids and disposal of drums containing liquids

Contacts:

Project Management:
Project Manager
Mr. Bill Goss
USACE, Seattle District
4735 Marginal Way, South

O&M Contractor:
URS Greiner Woodward-Clyde
2401 Fourth Avenue, Suite 1000
Seattle, Washington 98121
LTM - Kelly Teague
(206) 674-7931
O&M - Steffran Neff
(206) 343-7933

Regulatory Contact:
Mr. Bob Kievit
U.S. EPA Region X
Washington Operations Office
300 Desmond Drive, Suite 102
Lacey, Washington 98503
(360) 753-9014

Technology:
- Groundwater is extracted via two well fields located at the suspected main contaminant source area (The East Gate system), and from a line of wells located down gradient of the source areas (The I-5 system)
- Extracted groundwater is treated by air stripping
- Treated groundwater is recharged to the subsurface via wells and infiltration galleries near each extraction area

Type/Quantity of Media Treated:
- 2.147 Million gallons of water extracted, treated and recharged as of 8/98
- 2772 pounds of TCE removed as of 9/97

Regulatory Requirements/Cleanup Goals:
- Groundwater extracted at the Logistics Center Site is required to be treated to drinking water standards (MCLs) prior to recharge to the subsurface for the contaminants of concern: TCE - 5 mg/L; DCE - 70 mg/L
- Air emissions from the treatment systems are required to be below 75 pounds per month (I-5) and 325 pounds per month (East Gate), respectively

Results:
- Effluent sampling at each air stripper indicates that TCE concentrations in the treated groundwater are consistently below the treatment requirement of 5 mg/L. Several samples collected during the first few months of operation for the East Gate system contained TCE in concentrations exceeding 5 mg/L, however, operations have since been modified to improve performance of this system. No results above MCLs have been observed since October 1995. TCE removal efficiencies for the air strippers have ranged from 96 percent to greater than 99 percent since start up in 1995
- Air emissions have been below allowable limits for both treatment systems since since start up in 1995

Groundwater Extraction and Treatment at the Logistics Center Operable Unit, Fort Lewis, Washington

Costs:
The total cost incurred for design, construction and the first year of O&M for the two extraction and treatment systems was $5,208,000. The design cost was $1,251,000, and the construction cost was $3,528,000

Description:
The Logistics Center site at Fort Lewis covers 650 acres and is currently an active facility. The site was previously operated as an ordnance depot from 1942 to 1963 and has been operated as a non-aircraft maintenance facility since 1963. Groundwater at the Logistics Center has been contaminated with chlorinated organic compounds as the likely result of past disposal activities that included disposal of waste solvents in trenches excavated at the site. The principle contaminants of concern at the site are TCE and DCE. In 1990, a ROD was signed for the Logistics Center Operable Unit specifying that the contaminant plume be monitored and reduced over time, and that migration of groundwater contamination from the site be minimized.

In response to the ROD, it was determined that two extraction and treatment systems would be installed at the site. One system (the East Gate system) was designed to reduce the contaminant plume in the source area, and the other system (I-5) was designed to minimize off-site migration of contaminants. Both systems include treatment of contaminated groundwater using air stripping, followed by recharge of treated water to the subsurface. Recharge is accomplished using infiltration galleries located at each site and also by injection wells located at the East Gate site. The treatment systems have been in operation since 1995, and it is anticipated that treatment will continue for 30 years. The treatment systems each consistently meet federal and local requirements for treatment of groundwater prior to recharge and for allowable air emissions.

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IN SITU GROUNDWATER TREATMENT ABSTRACTS

In Situ Bioremediation Using Molasses Injection at an Abandoned Manufacturing Facility, Emeryville, California

Site Name:
Abandoned Manufacturing Facility

Location:
Emeryville, California

Period of Operation:
Pilot study - August 1995 to February 1996
Full scale system - ongoing, data available from April 1997 to October 1998

Cleanup Authority:
State voluntary cleanup program

Purpose/Significance of Application:
Bioremediation of a site contaminated with both chlorinated solvents and hexavalent chromium

Cleanup Type:
Pilot and Full scale

Contaminants:
TCE, hexavalent chromium
- Concentrations of TCE reported as high as 12,000 µg/L

Waste Source:
Electroplating operations

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Technology:
In situ bioremediation
- A pilot study was performed using a mixture of molasses, biologically inoculated solution (supernatant), and tap water was injected into the subsurface
- The full-scale system used 91 temporary injection points, installed to 24 ft bgs with a Geoprobe
- Molasses injection events were performed in April 1997 and February 1998, which involved a mixture of water, molasses, and a small amount of supernatant
- During the first injection event, each injection point received 25 gallons of molasses, 1 gallon of supernatant, and 125 gallons of water

Type/Quantity of Media Treated:
Groundwater
- Site geology consists of interbedded sand and clay units
- Depth to groundwater is approximately 3.5 to 8 ft
- Groundwater velocity is estimated at approximately 60 ft per yr

Regulatory Requirements/Cleanup Goals:
- The pilot study was performed to determine if TCE degradation and metal precipitation could be enhanced by an in situ reactive zone
- Cleanup goals for the full-scale application were not identified

Results:
- The average TCE concentration in on-site wells has decreased by 99% (3,040 µg/L in April 1995 to 4 µg/L in October 1998) during bioremediation
- The trends for TCE degradation products (cis-1,2-DCE and VC) indicate that TCE has been reductively dechlorinated to ethene under the engineered anaerobic conditions; initial cis-1,2-DCE and VC concentrations increased following the first reagent injection, but declined as shown in the October 1998 groundwater monitoring results
- The average concentrations of total chromium and hexavalent chromium in the injection area have been reduced by approximately 98% and 99%, respectively

Costs:
- The overall project cost was approximately $400,000

In Situ Bioremediation Using Molasses Injection at an Abandoned Manufacturing Facility, Emeryville, California

Description:
Metal plating operations were conducted at a manufacturing facility located in Emeryville, California (actual site name confidential) from 1952 until 1989. Investigations conducted at the site found groundwater to be contaminated with chlorinated solvents, primarily TCE, and hexavalent chromium. From August 1995 to February 1996, the site owner conducted a pilot study of anaerobic reductive dechlorination to evaluate its potential as a groundwater remedy under a state voluntary cleanup program. Based on the results of the pilot test, a full-scale system was installed and is operating at the site.

The injection of molasses reagent solution created conditions favorable for the reduction in TCE, DCE, VC, and chromium concentrations in the subsurface. During an 18-month period of full-scale operation, average concentrations of TCE were reduced by 99%, from more than 3,000 ug/L to 4 ug/L, and average concentrations of Cr+6 also were reduced by 99%. The pilot study showed that the rate of reductive dechlorination could be enhanced with the use of an injected molasses solution.

In Situ Bioremediation Using Molasses Injection at the Avco Lycoming Superfund Site, Williamsport, Pennsylvania

Site Name:
Avco Lycoming Superfund Site

Location:
Williamsport, Pennsylvania

Period of Operation:
Pilot study October 1995 to March 1996;
Full-scale system ongoing, data available through July 1998

Cleanup Authority:
CERCLA
- ROD signed December 1996

Purpose/Significance of Application:
One of the first applications of molasses injection technology on a full scale at a Superfund site

Cleanup Type:
Pilot and Full scale

Contaminants:
Chlorinated solvents and heavy metals - TCE, DCE, VC, hexavalent chromium, cadmium
- Maximum concentrations measured in late 1996 were TCE - 700 ug/L, hexavalent chromium - 3,000 ug/L, and cadmium - 800 ug/L

Waste Source:
Spills and leaks from plating operations; disposal in lagoons and wells

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Technology:
In Situ Bioremediation; Anaerobic Reductive Dechlorination
- Pilot studies consisted of molasses injection and air sparging/soil vapor extraction
- Full scale molasses injection system consists of 20 four-inch diameter injection wells, ranging in depth from 19 to 30 ft, completed in the overburden
- Molasses is added two times each day at variable concentrations and rates
- Eight additional wells are used for monitoring system performance
- This is a proprietary technology owned by ARCADIS Geraghty & Miller.

Type/Quantity of Media Treated:
Groundwater
- Site geology consists of a sandy silt overburden overlying a fractured bedrock and a fractured limestone
- Target area for treatment is the shallow overburden to approximately 25 ft bgs, covering approximately 2 acres

Regulatory Requirements/Cleanup Goals:
- The 1996 ROD specified the following cleanup goals for groundwater: TCE - 5 ug/L; 1,2-DCE - 70 ug/L; VC - 2 ug/L; Cd - 3 ug/L; Cr+6 - 32 ug/L; Mn - 50 ug/L

Results:
- The pilot study showed that the technology was able to create strongly reducing conditions
- The baseline sampling event showed that anaerobic, reducing conditions were present only near two of the site monitoring wells
- Since the injection of reagent, the redox levels have decreased to anaerobic conditions in many of the wells that had previously indicated an aerobic environment, and cleanup goals have been met in some of the wells
- Analytical results for TCE, DCE, and VC for an area that was converted from aerobic to anaerobic show that TCE was reduced from 67 to 6.7 ug/L, a 90% reduction. The concentration of DCE initially increased, indicating the successful dechlorination of TCE, and then decreased to 19 ug/L
- Concentrations of TCE, DCE, and Cr+6 have been reduced to less than their cleanup goals in many of the monitoring wells at the site

In Situ Bioremediation Using Molasses Injection at the Avco Lycoming Superfund Site, Williamsport, Pennsylvania

Costs:
- ARCADIS Geraghty & Miller reported a total project value of $145,000 for the pilot study application at this site, including preparation of a work plan
- The costs for the construction of the full scale molasses injection system was approximately $220,000. Operation and maintenance, including monitoring, is approximately $50,000 per year

Description:
The Avco Lycoming Superfund site (Lycoming) is a 28-acre facility located in Williamsport, Pennsylvania. Since 1929, various manufacturing companies have operated at the site. Past waste handling practices have contaminated the site, including disposal of waste in wells and lagoons, and spillage and dumping of wastes from metal plating operations. In 1984, the state identified volatile organic compound (VOC) contamination in the local municipal water authority well field located 3,000 ft south of the site. A pump and treat system was installed in the mid 1980's. In May 1995, the PRP proposed the use of in situ bioremediation to replace the pump and treat remedy. Pilot studies of molasses injection and air sparging/soil vapor extraction (SVE) were conducted from October 1995 to June 1996. A new ROD, issued in December 1996, replaced the pump and treat remedy with in situ bioremediation, and a full-scale system has been operating at the site since January 1997. Construction of the air sparging/SVE system was suspended in the Spring of 1998, due to higher than anticipated water levels.

The use of molasses injection was shown to create an anaerobic reactive zone in an 18-month period where concentrations of TCE, DCE, and hexavalent chromium were reduced. According to the PRP contractor, this technology was shown to save substantial resources when compared to pump and treat.

In Situ Bioremediation Using Bioaugmentation at Area 6 of the Dover Air Force Base, Dover Delaware

Site Name:
Dover Air Force Base, Area 6

Location:
Dover, Delaware

Period of Operation:
Proof of Technology Test: September 1996 to March 1998
Testing for Technology Scale-up: April 1998 to June 1999 (planned)
Full-scale System: Summer 1999 (planned)

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
The first successful bioaugmentation project using live bacteria from another site to treat TCE using reductive dechlorination

Cleanup Type:
Field demonstration (pilot proof of technology test)

Contaminants:
Chlorinated solvents
- Concentrations in the pilot area before the test were PCE - 46 ug/L, TCE - 7,500 ug/L, cis-DCE - 2,000 ug/L, and vinyl chloride - 34 ug/L

Waste Source:
Waste disposal

Contacts:

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Technology:
In Situ Bioremediation
- Groundwater flow and three-dimensional transport models (MODFLOW and MT3D) were used in designing the pilot system
- The pilot system included three extraction or pumping wells and three injection wells, each screened to a depth of 38 to 48 ft bgs, and designed to operate as an isolated or “closed-loop” recirculation cell
- The pumping wells were operated at a combined rate of 3.75 gpm (1.25 gpm each), providing a residence time of about 60 days for groundwater from the deep zone of the aquifer
- The extracted groundwater was filtered, and substrate (sodium lactate) and nutrients (ammonia and phosphate) were injected into the combined groundwater stream downstream of the filter
- On June 5 and 20, 1997, an aqueous culture (from the DOE’s Pinellas site in Largo, Florida; augmenting solution) was injected into the cell

Type/Quantity of Media Treated:
Groundwater
- The saturated portion of the formation consists of various sands and is about 38 feet thick
- The aquifer acts as one unconfined unit that includes three zones (approximately equal thickness) - an upper zone of fine sand (0 to 12 ft bgs), an intermediate zone of medium sand (12 to 25 ft bgs), and a deep zone also of medium sand (25 to 48 ft bgs)
- Groundwater is found in the intermediate and deep zones, starting at 10 to 12 ft bgs.
- Hydraulic conductivity was 60 ft/day and groundwater velocity 140 ft/yr

Regulatory Requirements/Cleanup Goals:
Pilot test goals: 1) demonstrate that TCE and PCE degradation can be stimulated in the deep portion of an aquifer; 2) confirm that degradation will proceed to nontoxic end products; 3) develop operation and cost data for a full-scale system; and 4) document the methodology used in the pilot system

In Situ Bioremediation Using Bioaugmentation at Area 6 of the Dover Air Force Base, Dover Delaware

Results:

- During the first five months of operation, the concentration of TCE gradually decreased, cis-DCE showed a slight increase, and there was no increase for vinyl chloride or ethene, indicating that limited dechlorination was occurring
- For the first 90-days following bioaugmentation, TCE concentrations continued to decrease and DCE concentrations continued to increase; however, there was no evidence of vinyl chloride or ethene in the groundwater
- By March 1998, all TCE and DCE in the groundwater were converted to ethene and between 75 and 80% of the TCE and DCE had been recovered as ethene, indicating that the bioaugmentation was successful in destroying TCE by reductive dechlorination
- From April 1998 through June 1999, the test was focusing on testing of parameters involved with technology scale up

Costs:

- Total capital costs were $285,563
- Total operating costs were $164,962 for the first three months of operation (through November 30, 1996) and $522,620 for the first fifteen months of operation (through November 30, 1997)
- According to the RTDF contact, a typical full-scale bioaugmentation system would cost substantially less than the system used in the pilot test at Dover

Description:

Dover Air Force Base (AFB), located in Dover, Delaware, is a 4,000 acre military installation that began operating in 1941. An estimated 23,000 cubic feet of waste, including solvents, waste fuels and oils, and a variety of other wastes, were disposed at the site from 1951 to 1970. Soil and groundwater at the base were found to be contaminated with volatile organic compounds, including TCE and PCE, and with heavy metals, including arsenic and cadmium. In March 1989, the site was listed on the National Priorities List. During a remedial investigation, “Area 6" was one of the areas at the base that was determined to have been contaminated with chlorinated solvents; a plume of VOCs was identified in groundwater in this area. Based on the results of that investigation as well as additional sampling, the area was selected for pilot testing of a bioaugmentation process. The remediation of Dover AFB is managed by EPA Region 3 and the Delaware Department of Natural Resources and Environmental Control. Interim RODs were signed in September 1995 that identify the following technologies for remediation at Dover: anaerobic reductive dehalogenation, cometabolic bioventing, and monitored natural attenuation. The pilot test was performed as part of the Bioremediation Consortium of the Remediation Technology Development Forum.

Data from the pilot test indicated that an extended period of time was required for the bacteria to exhibit functional dechlorination. At the start of bioaugmentation, lag periods of about 180 days between bioaugmentation and complete reduction of TCE and DCE to ethene were observed, including a 90-day lag period before vinyl chloride was first observed. Injection well plugging was a problem during the pilot test. Several methods were used to keep the wells unplugged including cleaning the well screens with wire brushes and pumping out residue from the screened interval, using hydrogen peroxide to clean the wells, and changing substrates from sodium lactate to lactic acid. Hydrogen peroxide proved the most effective technique for keeping the wells from clogging.

Aerobic Degradation at Site 19, Edwards Air Force Base, California

Site Name:
Edwards Air Force Base

Location:
California

Period of Operation:
February 5, 1996 to April 1, 1997

Cleanup Authority:
CERLCA

Purpose/Significance of Application:
Field demonstration of in situ bioremediation using groundwater recirculation wells to remediate TCE in a two aquifer system

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents

- Primary contaminant in groundwater- trichloroethene (TCE)
- Levels as high as 1,150 ug/L found in the groundwater; average TCE concentration in the upper and lower aquifer of 680 and 750 ug/L, respectively
- No 1,1-DCE found at the site prior to the demonstration

Waste Source:
Equipment cleaning and solvent degreasing operations

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Technology:
In Situ Bioremediation; Aerobic Degradation

- Two 8-in diameter, PVC treatment wells installed approximately 24 m deep and spaced 10 m apart; equipped with submersible pumps
- Each treatment well screened in both the upper (15 m) and lower aquifers (10 m)
- Groundwater recirculation - one well withdrew water from the upper aquifer and discharged it into the lower aquifer, while the other well withdrew water from the lower aquifer and discharged it into the upper aquifer creating a bioreactive treatment cell
- Initial flow rate - 38 liters per minute (L/min)
- Operation included groundwater pumping, pulsed addition of toluene, and addition of dissolved oxygen (DO, as gaseous oxygen) and hydrogen peroxide (H_2O_2)
- An area of 480 m^2 (0.12 acres) was monitored using 20 monitoring wells
- The demonstration included five phases, during which time the operating parameters were varied: pre-operational studies (days 0 - 33); establishment of a toluene-degrading consortium (days 34 - 55); pre-steady-state operation (days 56 - 136); steady-state operation (days 145 - 271); and balanced flow operation (days 317 - 444)

Type/Quantity of Media Treated:
Groundwater

- Volume of water in test area - 1,160 m^3
- Volume of water pumped - 12,132 m^3 from upper to lower aquifer; 16,063 m^3 from lower to upper aquifer
- Groundwater contaminant plume of approximately 53 acres
- Two relatively homogeneous aquifers - upper, unconfined aquifer is 8 m thick, and separated by a 2 m aquitard from the lower confined aquifer; lower, confined aquifer is approximately 5 m thick and lies above weathered bedrock

Regulatory Requirements/Cleanup Goals:

- The objectives of the field demonstration included evaluate the effectiveness of *in situ* bioremediation to treat TCE in groundwater and to collect data for potential full-scale application at the site
- Specific remedial goals were not established for the demonstration

Aerobic Degradation at Site 19, Edwards Air Force Base, California

Results:
- The system was found to be technically feasible for remediation of TCE in a two aquifer system
- TCE concentrations were reduced by 97.7%, from levels of up to 1,150 µg/L to 27 µg/L
- The average reduction of TCE during steady-state operation (days 145 - 271) was 87% in the upper aquifer bioactive zone and 69% in the lower aquifer adjacent to treatment well T1 discharge screen
- The average reduction of TCE during balanced flow operation (days 365 - 444) was 86% and 83% in the upper and lower aquifer bioactive zones, respectively
- No information was provided about potential degradation products from this demonstration

Costs:
- The total cost for the demonstration at Edwards AFB was $337,807, including $323,453 in capital costs and $14,354 in O&M costs

Description:
Edwards Air Force Base covers approximately 301,000 acres, is located on the western portion of the Mojave Desert, about 60 miles north of Los Angeles, and is used for aircraft research and development. From 1958 through 1967, rocket engines were maintained in facilities at the site. Spent TCE from maintenance operations was disposed at Site 19, a 53 acre area on the west side of Rogers Dry Lake. The resulting groundwater contaminant plume extends approximately 3,200 ft down-gradient from the source area. The site was added to the National Priorities List in August 1990. A Record of Decision (ROD) had not been signed for this facility at the time of this report.

Site 19 at Edwards Air Force Base was selected for a field demonstration to evaluate *in situ* bioremediation for the treatment of groundwater contaminated with TCE. The system used for the demonstration consisted of two treatment wells screened in both the upper and lower aquifers. One treatment well was used to withdraw water from the upper aquifer and discharged it into the lower aquifer, while the other treatment well was used to withdraw water from the lower aquifer and discharge it into the upper aquifer. This process recirculated the water between the two aquifers creating a bioreactive treatment cell. Treatment system operation included the pulsed addition of toluene, and the addition of dissolved oxygen and hydrogen peroxide (H_2O_2). The demonstration included steady-state and balanced flow operation. The results of the field demonstration showed that in situ bioremediation using groundwater recirculation was technically feasible for remediating TCE in a two aquifer system. TCE concentrations were reduced by 97.7%. The average reduction of TCE during steady-state operation was 69% to 87% in the lower and upper aquifer bioactive zones, respectively. The average reduction of TCE during balanced flow operation was 83% and 86% in the lower and upper aquifer bioactive zones, respectively. Prevention of well clogging was found to be an important operational concern for application of this technology. In this demonstration, site operators used well redevelopment and addition of hydrogen peroxide to control clogging.

In Situ Bioremediation at the Hanford 200 West Area Site, Richland, Washington

Site Name:
Hanford 200 West Area

Location:
Richland, Washington

Period of Operation:
January 1995 to March 1996

Cleanup Authority:
Not identified

Purpose/Significance of Application:
In situ bioremediation of chlorinated solvents and nitrate, including use of a computer-based tool to aid in system design and operating strategies

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated solvents
- Concentrations in groundwater at the demonstration site were approximately 2 mg/L for carbon tetrachloride (CCl_4) and about 250 mg/L for nitrate
- Estimated 600,000 kg of CCl_4 in soil and groundwater at demonstration site

Waste Source:
Chemical processing operations

Contacts:

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Technology:
In Situ Bioremediation
- One injection/extraction well pair (dual multi-screened wells) used to recirculate groundwater; two monitoring wells located between recirculation wells; a nutrient injection system; and a groundwater sampling system
- Groundwater was extracted and filtered, nutrients were added, and reinjected
- Nutrients consisted of acetate and nitrate pulses added at 24 hr intervals; the nitrate pulses were skewed 10 hrs from the acetate pulses
- An Accelerated Bioremediation Design Tool (ABDT) was used to determine pulse requirements
- Two separate tests were performed – one in the upper aquifer zone and one in the lower aquifer zone

Type/Quantity of Media Treated:
Groundwater
- The unsaturated zone is 75 m thick and uncontaminated
- Upper aquifer zone occurs at 75 - 78 m bgs; lower aquifer zone occurs at 87 - 92 m bgs; zones separated by low permeability unit and do not interact with each other significantly

Regulatory Requirements/Cleanup Goals:
Purpose of the demonstration was to evaluate the ability of the technology to degrade chlorinated solvents and to collect information about the use of ABDT

Results:
- Approximately 2 kg of CCl_4 were biodegraded during the upper and lower zone tests, with less than 2% conversion to chloroform
- CCl4 biodegradation rate – 0.8 mg/g-biomass/day in upper zone and 0.9 mg/g/day in lower zone
- The concentration of CCl_4 in the upper zone was reduced from approximately 2.0 to 1.2 mg/L after 100 days
- The upper zone test produced more than 20 kg of bacteria and the lower zone more than 10 kg (dry weight)
- No plugging of the injection well was observed
- The ABDT was used to design and operate an effective in situ bioremediation system for the demonstration

In Situ Bioremediation at the Hanford 200 West Area Site, Richland, Washington

Costs:

- An analysis of projected costs showed that the costs for in situ bioremediation were \$5.80/m^3, compared to \$13.30/m^3 for the baseline technology of air sparging/GAC; the treatment time was estimated as 1.9 yrs for ISB and 4.5 yrs for AS/GAC
- In situ bioremediation is cost-effective where plumes or portions of plumes are small enough for volumetric treatment (100 m diameter range), in aquifers where contaminant plumes exhibit non-equilibrium contaminant partitioning, and in source area plumes with significant contaminant sorption

Description:

The Hanford Site's mission has been to support national defense efforts through the production of nuclear materials. From 1944 to 1989, as part of the plutonium recovery processes, a variety of wastes including solvents, metals, and radionuclides were released to the soil and groundwater. Soil and groundwater at the 200 West Site Area at Hanford, located approximately 250 ft north of the sanitary tile field and 750 ft west of the 221-T plant, is contaminated with an estimated 600,000 kg of CCl_4. The 200 West Site Area was selected for a field-scale demonstration of in situ bioremediation. The demonstration included two separate tests, which were conducted in distinct, unconnected aquifer zones at the test site.

A recirculating well in situ bioremediation system was demonstrated at the 200 West Site Area, which showed reductions in the mass and concentration of CCl_4 in the two aquifer zones. Lessons learned from the field demonstration included that effective ISB system design and operational process control requires an ABDT or similar process simulator, and that use of an ABDT allows quick corrective action (such as changes in the amount/duration of nutrient pulse or the pulse period) to maintain rapid contaminant destruction during these changes. In addition, ISB was found to yield significant economic and efficiency gains over conventional baseline technologies for remediation of groundwater contaminated with VOCs and nitrates, and to be potentially effective for treating plumes caused by dissolution of non-aqueous phase liquids.

Aerobic Degradation at Moffett Naval Air Station, Mountain View, California

Site Name:
Moffett Naval Air Station

Location:
Mountain View, California

Period of Operation:
September 1986 to November 1988 (three seasons)

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
One of the earliest field demonstrations of aerobic in situ bioremediation under varying experimental conditions

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents
- 1,1,1-trichloroethane (TCA) and 1,1-dichloroethane (DCA) found in test zone; regulatory approval obtained for adding TCE, cis- and trans-DCE, and VC to the injected groundwater for demonstration

Waste Source:
Leaks and spills from aircraft and maintenance operations; disposal of waste in landfills

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Technology:
In Situ Bioremediation; Aerobic Degradation
- One extraction well and two injection wells used to create groundwater recirculation treatment cell
- TCE, cis- and trans-DCE, and VC injected into groundwater (regulatory approval obtained)
- Experiments conducted using native bacteria, methane addition, phenol and toluene addition, and hyfrogen peroxide addition; bromide tracer tests also performed

Type/Quantity of Media Treated:
Groundwater
- Test zone located in shallow, confined aquifer - 1.5 m thick; approximately 4 to 6 m bgs
- Hydraulic conductivity - 0.11 cm/sec; indigenous methanotrophic bacteria present in aquifer

Regulatory Requirements/Cleanup Goals:
- The objectives of the field demonstration included evaluating the performance of in situ biodegradation of chlorinated aliphatic hydrocarbons (CAHs) using native bacteria enhanced through addition of methane, toluene, and phenol
- Specific remedial goals were not established for this demonstration

Results:
- Methane addition was required for biodegradation of CAHs
- Removal rates for methane addition - TCE (20 - 30%), cis-DCE (45 - 55%), trans-DCE (80 - 90%), and VC (90- 95%); rate of TCE reduction remained relatively constant over three seasons of testing
- Use of phenol and toluene achieved higher percent removals of TCE (93 - 94%)
- Presence of 1,1-DCE was toxic to the transforming bacteria

Costs:
Not provided

Aerobic Degradation at Moffett Naval Air Station, Mountain View, California

Description:
Moffett Naval Air Station, used for aircraft operations and maintenance, operated from 1933 to 1994, and is located 35 miles south of San Francisco in Santa Clara County. In 1994, the Navy ceased operations and the airfield was transferred to the National Aeronautics and Space Administration. Soil and groundwater at the site are contaminated with petroleum products and VOCs, including TCE and PCE. Moffett was selected for a field demonstration of aerobic biodegradation and a series of experiments were conducted to evaluate the performance of the technology in treating CAHs using native bacteria enhanced through addition of methane, toluene, and phenol.

Results showed that active use of methane in the treatment zone was required for biodegradation of CAHs, and that groundwater residence times in the treatment zone of 1-2 days resulted in biodegradation of TCE, DCE, and VC. The use of phenol and toluene achieved higher percent removals of TCE (93 - 94%) compared with use of methane (19%), and hydrogen peroxide was found to achieve TCE removals similar to those achieved using oxygen. While 1,1-DCE was partially transformed in the study with phenol, the transformation products were toxic to the transforming bacteria. Therefore, the use of this technology when 1,1-DCE is present may not be appropriate. Alternating pulsed addition of methane and oxygen helped to prevent biofouling in the area near the injection well. According to the researchers, the relatively low concentration of phosphate in the groundwater did not limit the biodegradation of CAHs at this site; other phosphate minerals may have dissolved in the groundwater to replenish this mineral as it was being removed by the bacteria. The results from the field experiments were found to be consistent with the results from batch soil column laboratory testing using aquifer solids from the test zones.

Enhanced In Situ Anaerobic Bioremediation of Fuel-Contaminated Ground Water

Site Name:
Naval Weapons Station (NWS) Seal Beach

Location:
Southern CA

Period of Operation:
9/97 - 10/98

Cleanup Authority:
California Regional Water Quality Control Board

Regulatory Authority:
Lawrence Vitale
CARWQCB Region 8
2010 Iowa Ave, Suite 100
Riverside, CA 92507-2409
(909) 782-4130

Purpose/Significance of Application:
Demonstrate anaerobic bioremediation for treating fuel hydrocarbons

Cleanup Type:
Field demonstration

Contaminants:
Fuel hydrocarbons and BTEX

- Maximum concentrations in groundwater: benzene - 4,000 ug/L; ethylbenzene - 250 ug/L; m+p-xylenes - 500 ug/L

Waste Source:
Leaks from USTs

Contacts:

Project Management:
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Technology:
In Situ Bioremediation

- Demonstration used one extraction and three injection wells (three zones of 180 m^3 each)
- Extraction rate 4.5 L/min; injection 1.5 L/min/well
- Electron acceptors varied by zone - one zone augmented with sulfate, one with sulfate and nitrate, one with none; three rounds of augmentations performed
- Sampling performed with automated system

Type/Quantity of Media Treated:
Groundwater (in situ), Soil (in situ), LNAPL

- Contaminated area 20 acres, demonstration conducted on portion of site
- Groundwater velocity 0.7 cm/sec; transmissivity >2 ft^2/day; depth to groundwater low
- Groundwater had been anaerobic for >10 yrs

Regulatory Requirements/Cleanup Goals:

- Demonstrate the technical viability of the technology to treat petroleum hydrocarbons and to stimulate biodegradation of BTEX with nitrate and sulfate
- No specific cleanup goals were identified

Results:

- Concentrations of BTEX compounds were reduced, with toluene preferentially degraded
- Ethylbenzene and m+p-xylene degradation stimulated by nitrate, with concentrations reduced from 250 to <10 ug/L for ethylbenzene and from 500 to <20 ug/L for xylenes
- O-xylene degradation stimulated by sulfate, with concentration reduced from >400 to <10 ug/L
- Benzene removal was mostly due to flushing rather than biodegradation

Costs:

- Demonstration costs were $875,000, including equipment, labor, laboratory supplies, travel, and overhead; >9,000 samples were collected
- Projected present value costs for a full-scale bioremediation application were $1,085,000, or $4,340/gallon of fuel recovered, compared with similar costs for pump and treat of $1,530,000, or $6,120/gallon of fuel recovered

Enhanced In Situ Anaerobic Bioremediation of Fuel-Contaminated Ground Water

Description:
In 1984, a fuel leak was discovered at the Naval Weapons Station (NWS) Seal Beach when a steel tank was replaced with fiberglass tanks. NWS Seal Beach is located in southern California between Long Beach and Huntington Beach. About 5,800 gallons of fuel had leaked and migrated to the groundwater and was a concern for its potential effects on a local wildlife refuge.

A demonstration of in situ bioremediation was performed in a portion of the contaminated area of this site. The demonstration evaluated the performance of various concentrations of sulfate and nitrate in three zones between one extraction well and three injection wells. The results showed that concentrations of BTEX compounds were reduced, with toluene preferentially degraded. Ethylbenzene and xylenes also were degraded, but benzene was found to be removed mostly by flushing. Projected full-scale costs for in situ bioremediation were found to be approximately 30% less than for pump and treat. Lessons learned included the effect of BTEX compounds in a non-aqueous phase, the demand of non-BTEX fuel hydrocarbons on sulfate and nitrate, and the role of sulfate and nitrate as terminal electron acceptors.

In Situ Bioremediation (Anaerobic/Aerobic) at Watertown, Massachusetts

Site Name:
Not identified

Location:
Watertown, Massachusetts

Period of Operation:
Anaerobic: November 1996 to July 1997;
Aerobic: August 1997 to ongoing (data available through October 1997)

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Combined anaerobic/aerobic system for treatment of chlorinated solvents

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents
- TCE, PCE; initial TCE levels were 12 mg/L

Waste Source:
Manufacturing operations

Contacts:

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Technology:
In situ bioremediation
- A “two-zone” enhanced bioremediation process that used sequential anaerobic and aerobic biodegradation processes to degrade PCE and TCE; anaerobic conditions were used for eight months (through late July 1997), then changed to aerobic conditions
- The system was a groundwater recirculating cell that consisted of three injection wells and three extraction wells, and covered a surface area of approximately 10 ft by 20 ft; with wells screened from 13 to 20 ft bgs
- Nutrients and a carbon source were injected into the groundwater through the three up-gradient wells and extracted through the three down-gradient wells
- A relatively constant recirculating flow rate of 0.25 gpm was used along with an amendment injection rate of about four gallons per day (approximately 1% of the recirculating flow)
- Lactic acid was used in the anaerobic conditions, and ORC socks plus methane in aerobic conditions

Type/Quantity of Media Treated:
Groundwater
- Soil at the Watertown site consists of about 13 ft of sand and gravel over approximately 7 ft of silty sand
- Depth to groundwater is approximately 8 ft bgs

Regulatory Requirements/Cleanup Goals:
Purpose of the demonstration was to evaluate the use of a combined anaerobic and aerobic system for treatment of chlorinated solvent

Results:
- After four to five months of operation of anaerobic operation, significant increases in DCE were observed along with decreases in TCE concentrations, indicating that reductive dechlorination was occurring; no significant increases in VC concentrations were observed until July 1997, 8 months after operations began
- By July 1997, TCE concentrations had been reduced from about 12 mg/L at the beginning of the demonstration to less than 1 mg/L and there was an overall reduction of about 80% in the mass of total VOCs
- During the aerobic phase, levels of DCE and vinyl chloride have started to decrease in the groundwater; in addition, DCE epoxide, a transient biodegradation product of aerobic degradation of DCE, was detected, indicating that aerobic VOC-degrading bacteria have been stimulated

Costs:
- The field-scale pilot study has incurred a cost of approximately $150,000 through November 5, 1997
- No estimates were provided about the projected costs for a full-scale system using this technology

In Situ Bioremediation (Anaerobic/Aerobic) at Watertown, Massachusetts

Description:
The Watertown site has been used since the late 1800's for a variety of operations, including a coal gas manufacturing plant, which ceased operations in the 1930's, and a metal plating shop, which ceased operations in 1990. The site is currently being used as a manufacturing facility for electric switch assembly. Soil and groundwater at the site are contaminated with chlorinated solvents, including TCE and PCE, from past operations and waste disposal practices. A field demonstration of the Two-Zone Plume-Interception Treatment Technology, developed by Harding Lawson Associates (HLA, formerly ABB Environmental Services, Inc.), was conducted at the Watertown site under the Superfund Innovative Technology Evaluation (SITE) program. The field demonstration is currently ongoing.

Under anaerobic conditions, TCE in groundwater was reduced by reductive dechlorination (from 12 mg/L to less than 1 mg/L) and there was an overall reduction of about 80% of the total VOC mass in one well. Data indicate that methanogenic conditions were not achieved during the anaerobic phase and most of the reductive dechlorination was attributed to sulfate-reducing bacteria. A period of about one month was required to establish aerobic conditions after ORC socks were placed in the wells. This lag time was attributed to the presence of residual carbon that had to be degraded before aerobic conditions could be established. Initial results indicate that VOC levels, primarily DCE and vinyl chloride, are decreasing. According to EPA, future applications should consider not starting in the winter, start when the anaerobic process can go quickly, use a higher level of lactate, and drive the oxidation potential down quickly.

Methane Enhanced Bioremediation Using Horizontal Wells at the Savannah River Site, Aiken, South Carolina

Site Name:
U.S. DOE Savannah River Site

Location:
Aiken, South Carolina

Period of Operation:
February 26, 1992 to April 30, 1993

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Field demonstration of in situ bioremediation system using horizontal wells and methane injection

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents
- TCE and PCE concentrations in groundwater ranged from 10 to 1,031 ug/L and 3 to 124 ug/l, respectively
- TCE and PCE concentrations in sediment ranged from 0.67 to 6.29 mg/kg and 0.44 to 1.05 mg/kg, respectively

Waste Source:
Wastewater discharges from aluminum forming and metal finishing operations

Contacts:

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Technology:
In Situ Bioremediation
- Methane enhanced bioremediation
- Two horizontal wells used for the demonstration:
  - "lower" horizontal injection well - depth of 175 feet (below the water table); screen length of 310 feet; "upper" horizontal extraction well - depth of 80 feet (in the vadose zone); screen length of 205 feet
  - Air and gas injection rate - 200 scfm; air and contaminant extraction rate - 240 scfm
- Catalytic oxidizer used to treat the extracted vapors
- Demonstration performed in six different operational modes:
  - baseline tests of the vapor extraction and injection systems (with and without air sparging)
  - a series of nutrient additions (addition of 1% methane, 4% methane, pulsed 4% methane; and combination of nitrous oxide at 0.007% and triethyl phosphate at 0.07% in air in combination with pulses of 4% methane)
  - a helium tracer test
  - an assessment of microbiological assays for monitoring performance

Type/Quantity of Media Treated:
Groundwater and sediment
- VOC plume was estimated to cover about 1200 acres and to be about 150-ft thick
- Dense nonaqueous phase liquids (DNAPLs) have also been observed
- Depth to groundwater - 120 to 135 feet bgs
- Groundwater velocity - 15 to 100 feet/year

Regulatory Requirements/Cleanup Goals:
- Cleanup goals for groundwater included TCE (5 ppb) and PCE (5 ppb)
- Information was not provided about cleanup goals for sediment

Methane Enhanced Bioremediation Using Horizontal Wells at the Savannah River Site, Aiken, South Carolina

Results:

- After 384 days of operation, the system removed about 17,000 lbs of VOCs through a combination of vacuum extraction and biodegradation - the vacuum component of the system removed 12,096 lbs of VOCs and the biological component degraded 4,838 lbs of VOCs
- After treatment, the total sediment inventory for both TCE and PCE decreased by 24%, with the concentrations of VOCs in most sediment samples reported to be below the detection limits; concentrations of TCE and PCE in groundwater were reported to be less than 5 ppb; soil gas concentrations reportedly decreased by more than 99%
- The addition of methane stimulated the growth of methanotrophs - 1% methane addition increased the population of methanotrophs by several orders of magnitude, to levels close to 100,000 MPN/ml; 4% methane addition initially increased the population of methanotrophs, which then decreased as a result of nutrient depletion
- The addition of nitrogen and phosphorous nutrients with pulsed methane stimulated microbial activity. This phase was reported to optimize bioremediation and mineralization of TCE and PCE in groundwater and sediments
- Helium tracer tests indicated that more than 50% of the injected methane was consumed by indigenous microbes before it reached the extraction well; results were not provided from the microbiological assays

Costs:

- Projected costs for full-scale application at this site were $452,407 for total capital costs (including equipment amortized over 10 years, well installation, and mobilization) and $236,465 for operation and maintenance (including monitoring, consumables, and demobilization)

Description:

The U.S. Department of Energy (DOE) Savannah River Site (SRS) is a 300 square mile facility located in Aiken, South Carolina that has been used for the research and production of nuclear materials. Area M at the facility was used for aluminum forming and metal finishing operations. Wastewaters from this area containing an estimated 3.5 million pounds of solvents were discharged to an unlined settling basin, a process sewer line, and a nearby stream from the 1950's to the 1980's. High levels of chlorinated solvents, primarily TCE (up to 1,031 ug/L in groundwater and 6.29 mg/kg im sediment) and PCE (up to 124 ug/L in groundwater and 1.05 mg/kg in sediment), were found at the site and DNAPLs were observed. The VOC groundwater plume was estimated to cover about 1200 acres and to be about 150-ft thick.

From February 1992 to April 1993, DOE conducted a field demonstration of in situ methane enhanced bioremediation using two horizontal wells - one located below the water table and used for injection and one located in the vadose zone and used for extraction. A catalytic oxidizer was used to treat the extracted vapors. The demonstration was performed in six different operational modes, varying the type and concentration of nutrients added and the use of pulsing. During the demonstration, about 17,000 lbs of VOCs were removed through a combination of vacuum extraction and biodegradation. The addition of methane stimulated the growth of methanotrophs, with the addition of 1% methane increasing the population of methanotrophs by several orders of magnitude. Results of a tracer test showed that more than 50% of the injected methane was consumed by indigenous microbes before it reached the extraction well.

In Situ Bioremediation at the Texas Gulf Coast Site, Houston, Texas

Site Name:
Texas Gulf Coast Site (actual site name confidential)

Location:
Houston, Texas

Period of Operation:
Ongoing (data available from June 1995 to December 1998)

Cleanup Authority:
State of Texas Voluntary Cleanup Program; administered by TNRCC

Purpose/Significance of Application:
Groundwater recirculation system using trenches for extraction and injection

Cleanup Type:
Full scale

Contaminants:
TCE, cis-1,2-DCE, VC
- TCE was present at approximately 50 mg/L

Waste Source:
Leaks and spills from manufacturing operations

Contacts:

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Site Contact:
Not identified

Technology:
In situ bioremediation
- An extraction-injection recirculation system, completed in May 1995, consists of an alternating series of four extraction (1,800 linear ft total) and four injection (1,100 linear ft total) trenches set at a spacing of approximately 100 ft
- The extraction trenches were completed to a depth of at least one foot into the bottom clay layer (20 - 22 ft bgs), and were sloped to a sump
- System operation consists of groundwater circulation and addition of methanol
- As of January 1999, the recirculation rate averages 6 to 8 gpm, and a total of 12 million gallons have been recirculated through the system (approximately 2.5 pore volumes)

Type/Quantity of Media Treated:
Groundwater
- The area of contaminated groundwater is approximately 600 ft by 700 ft in an unconsolidated water-bearing zone which occurs at a depth of approximately 12 - 20 ft bgs
- Hydraulic conductivity is 1×10^{-4} to 4×10^{-4} cm/sec
- Groundwater velocity is 4 - 18 ft/yr

Regulatory Requirements/Cleanup Goals:
- The primary objectives of the clean up are to actively remediate the contaminated groundwater at this site to a point that natural attenuation would prevent further migration of the plume, and to discontinue active treatment
- No specific cleanup goals have been identified for groundwater at this site

Results:
- Excluding results from the one potential “source” area, the average decrease in TCE concentrations is approximately 99% (from an average of 12 to 0.12 mg/L) during a 3 ½ year period
- TCE concentrations in portions of the plume have decreased to below the detection limit (0.005 mg/L).
- Accounting for dilution, the site contractor reported that TCE concentrations were reduced by approximately 2% per month during a period of nutrient-only addition, and approximately 10% per month during the period of methanol addition
- The ratio of cis-1,2-DCE to TCE increased from approximately 0.06:1 to 0.30:1 after addition of methanol, suggesting more active dechlorination associated with higher concentrations of substrate.

Costs:
- Capital costs for construction of the extraction/injection trenches and control building were approximately $600,000
- Annual costs for operation, maintenance and monitoring are approximately $100,000

In Situ Bioremediation at the Texas Gulf Coast Site, Houston, Texas

Description:
The Texas Gulf Coast site is an abandoned industrial manufacturing facility located near Houston, Texas that operated between 1952 and 1985. Trichloroethene was used at the facility and was found in the groundwater starting in 1986. In situ bioremediation is being used to clean up groundwater at the site under the State of Texas Voluntary Cleanup Program.

Methanol addition was found to increase the rate of biodegradation of TCE at this site, based on the reduction of TCE concentration and increase in the ratio of cis-1,2-DCE to TCE. This site is planning to stop using active bioremediation after four years of system operation (three years of methanol addition) to allow use of natural attenuation. According to the site contractor, natural attenuation will be used to prevent future migration of the plume, and to achieve stable or declining contaminant concentrations. Excessive biomass formation, leading to a reduced flow rate, was found to be a concern for addition of methanol. Excess biomass was not noted during the period when nutrients alone were added; however, a significant increase in biomass formation was noted after addition of methanol. To remedy this, the site contractor modified their methanol addition to a batch system. The site contractor found that it was difficult to balance the system hydraulics between the extraction and infiltration trenches, and that it required approximately one year of operating time to achieve a balance. In addition, they found it difficult to interpret the treatment performance data because of the non-homogeneous nature of the initial groundwater quality, and dilution due to recharge of rainwater and clean water from beyond the planned treatment area.

In Situ Redox Manipulation at U.S. DOE Hanford Site, 100-H and 100-D Areas

Site Name:
U.S. Department of Energy Hanford Site, 100-H and 100-D Areas

Location:
Richland, WA

Period of Operation:
September 1995 to September 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstrate in situ redox manipulation for treatment of hexavalent chromium

Cleanup Type:
Field demonstration

Contaminants:
Chromium
- Initial chromate concentrations 60 ug/L in 100-H area and 910 ug/L in 100-D area

Waste Source:
Nuclear processing operations

Contacts:

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Technology:
In Situ Redox Manipulation (ISRM)
- The field demonstration used 20,500 gallons of buffered sodium dithionite solution ($Na_2S_2O_4$, also known as hydrosulfite) to react with natural iron in the subsurface and form reduced iron (Fe^{2+}); the reduced iron reacts with chromate to form insoluble chromium oxides
- Dithionite solution was injected through one 8-inch diameter injection/extraction well, allowed to react for 18 hrs, and then withdrawn; this created a reduced zone 50 ft in diameter
- The withdrawal phase took 83 hrs and 4.8 injection volumes to remove unreacted reagent, buffer, reaction products, bromide tracer, and mobilized metals
- 16 two-inch monitoring wells were used to assess physical and chemical conditions after the test

Type/Quantity of Media Treated:
Groundwater
- Depth to groundwater is 50 ft in 100-H area and 85 ft in 100-D area
- Aquifer is 15-20 ft thick

Regulatory Requirements/Cleanup Goals:
- Evaluate performance of ISRM for treating chromium in groundwater
- No specific cleanup goals were identified

Results:
- Concentrations of chromium in groundwater were reduced to less than 8 ug/L in one month
- 87-90% of the dithionite solution was recovered during the withdrawal phase, along with most of the mobilized metals (Fe, Mn, Zn)
- Within 25 ft of the injection well, 60-100% of the available iron was reduced; this zone was estimated to have a life of 7-13 yrs
- Two years after treatment was complete, the treatment zone remained anoxic and hexavalent chromium below detection limits

Costs:
- Projected costs for use of ISRM in a full-scale deployment at this site were identified using two methodologies (one for a 200 ft barrier and one for a 1,400 ft barrier), both in comparison to projected costs for pump and treat; this analysis showed cost savings for use of ISRM of $4.6 to 16 million

In Situ Redox Manipulation at U.S. DOE Hanford Site, 100-H and 100-D Areas

Description:
The 100 Area of the Hanford site contains nine nuclear reactors, and is located in the north-central portion of the site near the Columbia River. During reactor operations, chromium was introduced to the soil and groundwater in this area.

A demonstration of in situ redox manipulation (ISRM) was conducted in the 100-H and 100-D areas at Hanford that consisted of field-scale demonstrations. ISRM is a passive barrier technique that uses injection of buffered sodium dithionite solution ($Na_2S_2O_4$) to react with natural iron in the subsurface and form reduced iron (Fe^{2+}); the reduced iron reacts with chromate to form insoluble chromium oxides. Results from the field demonstration test showed that initial chromate concentrations of 60 ug/L in the 100-H area and 910 ug/L in the 100-D area were reduced to less than 8 ug/L in a one month period. In addition, 87-90% of the dithionite solution was recovered during the withdrawal phase, along with most of the mobilized metals (Fe, Mn, Zn). A full-scale deployment for the Hanford 100-HR-3 operable unit is planned to begin in late 1999.

In Situ Chemical Oxidation Using Potassium Permanganate at Portsmouth Gaseous Diffusion Plant, X-701B Facility

Site Name:
Portsmouth Gaseous Diffusion Plant, X-701B Facility

Location:
Piketon, OH

Period of Operation:
Spring 1997 (operated for one month)

Cleanup Authority:
RCRA Corrective Action

Purpose/Significance of Application:
Demonstrate in situ chemical oxidation for treating chlorinated solvents

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated solvents
- Initial TCE concentrations in groundwater averaged 176.7 mg/L

Waste Source:
Leaks from USTs

Contacts:

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Technology:
In Situ Chemical Oxidation
- Demonstration used a pair of parallel horizontal wells - one to extract groundwater (6 gpm) and one to reinject after addition of potassium permanganate ($KMnO_4$)
- Each well had a 200 ft screened section located in a 5 ft thick silty, gravel aquifer in the center of a plume
- Crystalline $KMnO_4$ was added to the extracted groundwater and reinjected into the downgradient well 90 ft from the extraction well; a total of 206,000 gals of $KMnO_4$ solution was injected
- Oxidant solution (~2% $KMnO_4$) was recirculated for one month
- Delivery of oxidant solution was not uniform throughout the horizontal well; a subsequent injection of $KMnO_4$ was made into a nearby vertical well for 8 days to enhance delivery
- System shutdowns were due to heavy rains, well-screen clogging, and repairs

Type/Quantity of Media Treated:
Groundwater (in situ)
- The Gallia sand and gravel unit was the target for the demonstration
- DNAPL compounds (mostly TCE) were located 25-35 ft bgs, 12 ft below top of water table
- Area of contamination approximately 90 ft by 220 ft by 6 ft (119,000 ft^3) containing 272.7 lbs of TCE

Regulatory Requirements/Cleanup Goals:
- Evaluate performance of the technology in degrading TCE
- No specific cleanup goals were identified

Results:
- Average concentrations of TCE were 176.7 mg/L before treatment, 110 mg/L at completion of treatment, and 41 mg/L two weeks after recirculation ended; concentrations increased to 65 mg/L at 8 weeks and 103 mg/L at 12 weeks after recirculation ended
- Immediately after recirculation ended, concentrations of TCE were low (BDL to low ug/L) in monitoring wells where $KMnO_4$ was also detected
- Residual concentrations of $KMnO_4$ were detected at nine monitoring well locations 19 months after the demonstration ended

In Situ Chemical Oxidation Using Potassium Permanganate at Portsmouth Gaseous Diffusion Plant, X-701B Facility

Costs:

- The estimated cost for the demonstration was \$562,000, consisting of project management (\$67,440), pre-demonstration characterization (\$162,980), remediation operations/oxidant recirculation (\$162,980), resistivity monitoring (\$67,440), and post-demonstration characterization and demobilization (\$101,160)
- Projected costs for use of the technology at a full-scale were \$516,360, to treat a hot spot area of 22.9 acres in the central portion of the X-701B plume; this corresponds to \$64/yd^3

Description:

The Portsmouth Gaseous Diffusion Plant (PORTS), located 80 miles south of Columbus, Ohio, is a 3,714-acre DOE reservation. It was constructed between 1952 and 1956 and enriches uranium for electrical power generation. The X-701B site, located in the northeastern area of PORTS, contains an unlined 200 ft by 50 ft holding pond. The pond was used from 1954 to 1988 for neutralization and settling of metal-bearing acidic wastewater and solvent-contaminated solutions. During a RCRA Facility Investigation, TCE was detected in a groundwater sample at 700 mg/L.

A field demonstration of in situ chemical oxidation was conducted at PORTS using a pair of parallel horizontal wells – one for extraction and one for reinjection. Crystalline $KMnO_4$ was added to extracted groundwater and reinjected into the downgradient well 90 ft from the extraction well; a total of 206,000 gals of $KMnO_4$ solution was injected and recirculated for one month. Results showed that immediately after recirculation ended, concentrations of TCE were low (BDL to low ug/L) at those locations where $KMnO_4$ was detected in the monitoring well. However, oxidant addition was not uniform and average concentrations were higher - 110 mg/L at completion of treatment, and 41 mg/L two weeks after recirculation ended. The researchers concluded that the number and pattern of extraction and injections wells must be designed to ensure maximum coverage of the treatment zone.

Phytoremediation Using Constructed Wetlands at the Milan Army Ammunition Plant, Milan, Tennessee

Site Name:
Milan Army Ammunition Plant

Location:
Milan, Tennessee

Period of Operation:
June 17, 1996 to July 21, 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Use of constructed wetlands for treatment of explosives-contaminated groundwater

Cleanup Type:
Field demonstration

Contaminants:
Explosives
- Total nitrobody (the sum of the following six explosives: TNT, RDX, HMX, TNB, 2A-DNT, and 4A-DNT) concentrations in groundwater ranged from 3,250 to 9,200 ppb
- TNT concentrations in groundwater ranged from 1,250 to 4,440 ppb
- RDX concentrations in groundwater ranged from 1,770 to 4,240 ppb
- HMX concentrations in groundwater ranged from 87 to 110 ppb

Waste Source:
Industrial wastewater discharged to ditches

Contacts:

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(601) 634-2435
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Technology:
Constructed Wetlands
- Two types of wetlands were demonstrated - a gravel-based system and a lagoon-based system
- Both systems were designed to retain groundwater for approximately 10 days at an influent flow rate of 5 gpm per system
- The gravel system consisted of two 4 ft deep gravel-filled beds (cells) connected in series and planted with emergent plants; the first cell (0.088 acre) was maintained as anaerobic (by carbon addition) and the second cell (0.030 acre) as aerobic; emergent plants used were canary grass, wool grass, sweetflag, and parrotfeather
- The lagoon system consisted of two 2 ft deep lagoons (cells) connected in series and planted with submergent plants
- The demonstration was conducted in three phases - (I) plant screening and treatability studies; (II) design, construction, and 16 months of monitoring; and (III) longer-term monitoring and optimization

Type/Quantity of Media Treated:
Groundwater
- Groundwater flow north-northwest

Regulatory Requirements/Cleanup Goals:
- Reduce concentration of TNT to less than 2 ppb, and total nitrobody concentrations (see contaminants) to less than 50 ppb

Phytoremediation Using Constructed Wetlands at the Milan Army Ammunition Plant, Milan, Tennessee

Results:
- The gravel-based system performed better than the lagoon-based system
- The gravel system reduced TNT, RDX, and HMX concentrations to below the cleanup goals during all but the coldest months; in addition, a sustainable ecosystem was established
- The lagoon system met the cleanup goal for TNT of 2 ppb only during the first 50 days of the demonstration, but did not remove RDX and HMX or meet the total nitrobody goals; in addition, an adequate plant population was not maintained within the lagoon system

Costs:
- Projected costs for a 10-acre, full-scale, gravel-based system designed to treat 200 gpm of contaminated groundwater at Milan AAP were $3,466,000 ($1998).
- Assuming a 95% system availability and 30-yr life, the total cost (capital plus O&M) for use of this system was estimated as $1.78 per 1,000 gals of groundwater

Description:
The Milan Army Ammunition Plant (MAAP) is a government-owned, contractor-operated military industrial installation within the U.S. Army Industrial Operations Command. The original facility was constructed during World War II. MAAP is located on 22,436 acres of land, which include approximately 548 acres for various production lines, 7,930 acres for storage areas, and 1,395 acres for administrative, shop maintenance, housing, recreation, and other functions. From World War II to 1981, MAAP's production facilities discharged explosives-contaminated wastewater directly into open ditches that drained from sumps or surface impoundments into local streams. Several of these drainage ditches became contaminated with explosive residuals which leached into the groundwater. In 1981, the production facility's wastewaters were redirected to explosives-contaminated wastewater treatment plants.

A wetlands demonstration system was constructed in Area K adjacent to Building K-100. The demonstration consisted of gravel- and lagoon-based systems, and was conducted over a two-year period. The study found that the gravel-based system had results better than the lagoon system, and met the goals during all but the coldest months. The lagoon system did not consistently meet the goals, and had several operational problems, including a severe tadpole infestation and a hailstorm. The demonstration study authors concluded that a wetland's economic and technical feasibility depends on site-specific factors such as regional temperature variations, rainfall patterns, groundwater flow characteristics, explosive type and concentration, the presence of other contaminants, and regulatory requirements. In general, they found that wetlands perform better in warmer climates with moderate levels of rainfall.

Multi-Phase Extraction at the 328 Site, Santa Clara, CA

Site Name:
328 Site

Location:
Santa Clara, CA

Period of Operation:
November 19, 1996 to May 4, 1999
Shutdown period to assess rebound: June 5, 1998 through September 8, 1998

Cleanup Authority:
State of California San Francisco Bay Regional Water Quality Control Board

Purpose/Significance of Application:
Use of DPE with pneumatic fracturing to remove VOCs from silty clay soils and shallow groundwater

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents

- Trichloroethene (TCE) is the primary contaminant of concern, with the highest TCE concentration measured in the soil and groundwater during the remedial investigation at 46 mg/kg and 37,000 ug/L, respectively

Waste Source:
Storage of waste from vehicle manufacturing operations

Contacts:

Vendor:
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HSI GeoTrans
3035 Prospect Park Drive, Suite 40
Rancho Cordova, California 95670,
Tel: 916-853-1800
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State Contact:
Mr. George Lincoln
State of California
Regional Water Quality Control Board
San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, CA 94612

Additional Contacts:
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Environmental Project Manager
FMC Corporation
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Santa Clara, California 95052
Tel: 408-289-3141
Fax: 408-289-0195
E-mail: zahra_zahir@udlp.com

Technology:
Dual Phase Extraction (DPE) with Pneumatic Fracturing System

- 20 dual phase, single pump extraction wells installed at the source area
- 41 fracture locations (two pneumatic fracture points installed between each pair of extraction wells)
- Following initial fracturing, a low flow/low pressure compressor provided continuous air injection into each fracture point
- Groundwater extraction rate - approximately 35 gpm on a continuous basis
- Average vapor flow rate - increased from approximately 39 scfm to over 65 scfm, following pneumatic fracturing

Type/Quantity of Media Treated:
Soil and Groundwater

- Depth to groundwater - 8 ft bgs; the first water-bearing zone (A-level aquifer) present at 20 to 50 ft bgs; second water-bearing zone (B-level aquifer) present 50 to 90 ft bgs
- Sediments underlying the site include marine or basinal clays, coarse channel deposits, and inter-channel silts and clays

Regulatory Requirements/Cleanup Goals:

- Less than 10 mg/L total VOCs in soil.

Results:

- The DPE system removed approximately 1,220 pounds of VOCs from the source area
  - VOC mass removed by soil vapor extraction - 782 pounds
- Average source area VOC concentration in groundwater declined from over 12,000 ug/L to less than 800 ug/L
- During first month of operation, about 40% of the mass of VOCs removed was from the vadose zone; by the fifth month, groundwater extraction was removing more VOC mass than SVE
- DPE system shut down June through August 1998 to assess rebound
  - VOC concentrations remained relatively constant during shut down and after restart
- 27 confirmation soil samples averaged 0.93 mg/L total VOCs

Multi-Phase Extraction at the 328 Site, Santa Clara, CA

Costs:

- The cost to design and install the DPE system with pneumatic fracturing was approximately $300,000.
- Approximate costs for two years of operation and maintenance services, reporting, and analytical fees were $450,000, averaging $225,000 per year. Approximately $100,000 was required for the disposal of spent carbon.
- The unit cost for treatment of the 0.5-acre source area from 0 to 20 feet bgs was $53 per cubic yard of soil (for treatment of 16,000 yd^3)

Description:

The 328 Site occupies approximately 27.1 acres in a primarily industrial and commercial area of San Jose and Santa Clara, California, near the San Jose Airport. The 328 Site was used for manufacturing military tracked vehicles, including assembly and painting operations, from 1963 through 1998. A former waste storage area was the suspected source of VOC contamination of soil and groundwater at the site. The cleanup of the 328 Site was performed in anticipation of future commercial/industrial redevelopment and was conducted by FMC Corporation in accordance with the State of California San Francisco Bay Regional Water Quality Control Board *Final Site Cleanup Requirements Order Number 96-024*.

A DPE system, which included 20 dual phase, single pump extraction wells, was used to remove VOCs from silty clay soils and shallow groundwater at the site Air flow through the soils was enhanced by pneumatic fracturing (PF) between DPE extraction wells and by supplying continuous low flow/low pressure air to the fractured soils. Over 40 percent of the VOC mass removal occurred from the vadose zone during the first month of operation. Groundwater extraction provided greater mass removal rates than soil vapor extraction by the fifth month of operation. The combination of technologies has allowed soil vapor extraction to be effective in an area that is not well suited for in-situ remediation.

Dual Phase Extraction at the Defense Supply Center, Richmond, Virginia

Site Name:
Defense Supply Center, Acid Neutralization Pit (ANP)

Location:
Richmond, VA

Period of Operation:
July 1997 - July 1998

Cleanup Authority:
CERCLA - Remedial Action
- ROD signed 1992
- ESD signed 1995

Purpose/Significance of Application:
Use of DPE to treat soil and groundwater contaminated with chlorinated solvents, including PCE and TCE

Cleanup Type:
Treatability study

Contaminants:
Chlorinated Solvents
- The highest concentrations of VOCs detected in the upper aquifer were 3300 micrograms per liter (μg/L) for PCE, 890 μg/L for TCE, and 26 μg/L for 1,2-DCE; VOCs were not detected in the lower aquifer

Waste Source:
Leaks from settling basins that received wastewater from metal plating operations

Contacts:

Vendor:
Katy L. Allen, P.E.
Law Engineering and Environmental Services, Inc.
112 Town Park Drive
Kennesaw, GA 30144
Tel: (770) 421-3400

Regulatory Contact:
Stephen Mihalko
Remedial Project Manager
Virginia Department of Environmental Quality
P.O. Box 10009
Richmond, VA 23240
Tel: (804) 698-4202

Todd Richardson
U.S. EPA Region 3
1650 Arch Street (MC 3HS50)
Philadelphia, PA 19103-2029
Tel: (215) 814-5264
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Additional Contacts:
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DSCR Remedial Project Manager
Defense Supply Center Richmond
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Richmond, VA 23297-5000
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Technology:
Dual Phase Extraction (DPE)
- 12 DPE wells and six air injection wells arranged in a rectangular grid
- DPE wells installed to depth of 22 to 28 ft bgs (10 ft screen length) and equipped with an electric, submersible (variable-frequency drive) pump,
- SVE vacuum at blower - 42 in WC; SVE air flow rate - 314 cfm
- Groundwater extraction rate - 37 gpm
- DPE radius of influence - 600 to 800 ft, downgradient
- Air extracted by the SVE blower was vented to the atmosphere. Extracted groundwater was pumped directly to a low-profile tray type air stripper to remove VOCs. Air stripper off-gas was released to the atmosphere
- Effluent water was discharged to a storm sewer that flows to a nearby stream.

Type/Quantity of Media Treated:
Soil and Groundwater/17 million gallons of groundwater recovered and treated
- The plume area was estimated to be 16,000 square feet
- Depth to groundwater - 10 to 15 ft bgs; hydraulic gradient - 0.001 to 0.002 ft/ft; aquifer transmissivity - 374 to 504 ft^2/d

Dual Phase Extraction at the Defense Supply Center, Richmond, Virginia

Regulatory Requirements/Cleanup Goals:

- Remedial goals for PCE - 5 μg/L and TCE - 5 μg/L, or attainment of an asymptotic trend in contaminant of concern concentrations in groundwater (whichever occurs first)
- The purpose of the DPE treatability study was to collect additional operational data to refine system design parameters, and to evaluate the effectiveness of an air injection system to facilitate air flow through soils exposed by drawdown of the groundwater surface

Results:

- Total VOC concentrations were reduced by more than 99% in several wells; for example, in two wells located in the plume center initial concentrations of total VOCs were reduced from 1,980 μg/L to 11.9 μg/L and from 1,766 μg/L to 3.5 μg/L
- Total mass of VOC removed - 145 lb:
  - Groundwater VOC mass removal rate - 28 lb (0.09 lb/d) total, including 2 lb (<0.01 lb/d) aromatic and 26 lb (0.08 lb/d) chlorinated
  - Soil VOC mass removal rate - 117 lb (0.37 lb/d) total, including 70 lb (0.22 lb/d) aromatic and 47 lb (0.15 lb/d) chlorinated
- At the completion of the treatability study, PCE and TCE concentrations remained above the remedial goals in several wells, and increasing VOC concentrations were observed in wells at the outer edge of the radius of influence of the DPE system

Costs:

- The total cost for the one year treatability study of the DPE system was $538,490, including $134,092 for pre-design investigations supporting DPE design, $73,198 for engineering design of the DPE system, $205,743 in system construction costs (equipment only), $24,309 in startup costs, and $101,148 in operation and maintenance, which included the cost of sample collection and analysis
- The total cost per unit volume of groundwater recovered and treated was $0.03 per gallon (based on 17 million gallons of groundwater)

Description:

The 640-acre Defense Supply Center Richmond (DSCR) is a military support, service, and storage facility located approximately 11 miles south of the City of Richmond, VA. Since 1942, DSCR has been furnishing and managing general military supplies to the Armed Forces and several federal civilian agencies. Historic and current industrial operations at the DSCR have included repair of equipment, engine rebuilding, and refurbishment of combat helmets and compressed gas cylinders. The Acid Neutralization Pit (ANP) site, located in the northern section of the DSCR, consists of two former concrete settling basins that received wastewater from metal cleaning operations conducted at one of the warehouse buildings. In 1985, when the tanks were closed, they were observed to be cracked and broken. Site investigations determined that the groundwater was contaminated with chlorinated solvents, primarily tetrachloroethene (PCE) and trichloroethene (TCE). The site was placed on the National Priorities List. A ROD, signed in 1995, addressed the contamination at the ANP site, and the results of the Feasibility Study identified DPE as a potentially viable remediation alternative for the site.

A pilot test of the DPE system, along with aquifer testing, was performed in June 1995 to gather site-specific hydrogeologic data and data on air extraction rates and SVE mass removal rates. The results of the testing supported the use of DPE for VOC recovery at DSCR. A full-scale system, consisting of 12 DPE wells and six air injection wells were installed and a treatability study was conducted for one year to evaluate the effectiveness of the full-scale system, including collecting operational data to refine system design parameters, and to evaluate the effectiveness of the air injection system. After one year, the DPE system removed 145 pounds of VOCs, including 117 pounds from the soil vapor and 28 pounds from the groundwater. Although VOC concentrations were reduced in a number of wells, including reductions of more than 99% in two wells located withing the plume, concentrations of PCE and TCE remained above the cleanup goals in several wells. Based on the results of the treatability study, the Army's contractor recommended that the DPE system continue operation and that additional investigations be done to better define the capture zone of the system. The unit cost was $0.03 per gallon based on 17 million gallons of groundwater treated during the pilot test.

Dual Vapor Extraction at Tinkham’s Garage Superfund Site, Londonderry, NH

Site Name:
Tinkham’s Garage Superfund Site

Location:
Londonderry, NH

Period of Operation:
November 22, 1994 to September 29, 1995

Cleanup Authority:
CERCLA
- ROD signed 1985
- ROD amended March 1989

Purpose/Significance of Application:
Use of DVE to treat soil and groundwater contaminated with chlorinated solvents, including PCE and TCE

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents
- Tetrachloroethene (PCE) and trichloroethene (TCE)
- Site investigations found total VOCs as high as 652 ppm in soil and 42 ppm in groundwater

Waste Source:
Discharges of liquids and sludge to surface soils

Contacts:

Vendor:
Joleen Kealey
Project Manager
Terra Vac, Inc.
213 Rear Broadway
Methuen, MA 01844
Tel: (978) 688-5280

EPA RPM:
James DiLorenzo
U.S. EPA Region 1 (MC:HBO)
One Congress Street, Suite 1100
Boston, MA 02114-2023
Tel: (617) 918-1247
E-mail: dilorenzo.jim@epa.gov

Technology:
Dual Vapor Extraction (DVE)
- 33 DVE wells divided into 25 shallow DVE wells, screened in the overburden, and 8 deep DVE wells, screened in the upper bedrock and overburden; five existing pilot test wells were left in place and used for vapor extraction; the wells were distributed over three manifold lines
- SVE vacuum at blower - 5 in Hg (≈68 in WC)
- SVE flow rate - 500 scfm, average
- Vapors treated using activated carbon; recovered groundwater treated using air stripping to meet the Derry POTW pre-treatment standards; off-gas from air stripper treated using vapor phase carbon

Type/Quantity of Media Treated:
Soil and Groundwater/9,000 cubic yards of soil treated
- Overburden consisting of inorganic and organic silty clay and sand grading to fine and medium-grained sand; weathered metamorphic bedrock at approximately 14 feet bgs
- Depth to groundwater - 5 to 6 feet bgs
- Hydraulic conductivity - range 1 ft/d to 10 ft/d

Regulatory Requirements/Cleanup Goals:
- ROD specified 1 ppm total VOCs for soil and 5 ppb each for PCE and TCE in groundwater

Results:
- Soil cleanup goals were achieved within ten months of operation; groundwater cleanup goals were not achieved at the conclusion of DVE system operation and pump-and-treat has been implemented as the site
- Approximately 53 pounds of VOCs were removed by the DVE system:
  - vapor extraction removed approximately 48 pounds; averaging 0.17 pounds per day
  - groundwater extraction removed approximately 5 pounds of VOCs (recovered in the aqueous phase); averaging 0.016 pounds per day
- The majority of VOCs recovered were PCE and TCE
- VOCs extracted in the vapor phase were reduced from concentrations as high 16 ppm to below 1 ppm (the soil cleanup goal)
- Concentrations of VOCs in groundwater in the source area decreased by over 99% in one well and by 64% in a second well. However, total VOCs concentrations in groundwater remained above the cleanup goals and ranged from 29 to 237 ppb in the source area

Dual Vapor Extraction at Tinkham's Garage Superfund Site, Londonderry, NH

Costs:

- The actual cost for the project, not including permitting and oversight, was $1.5 million, or $170/cy (based on 9,000 cy of soil treated).
- This cost includes an adjustment for inflation

Description:

The Tinkham's Garage Superfund site includes 375 acres of residential and undeveloped land in Londonderry, NH. Site investigations in 1981 found soil and groundwater contaminated with VOCs, including PCE, and TCE, resulting from unauthorized surface discharges of liquids and sludge in 1978 and 1979. Several source areas were identified at the site including areas near a condominium complex and a one acre area located behind Tinkham's Garage ("Garage Area"). The original 1985 ROD for the site specified excavation of contaminated soil with onsite treatment by either thermal aeration, composting, or soil washing. As a result of the pre-design and pilot studies, the ROD was amended in March 1989 to require the treatment of contaminated soil by DVE. For cost purposes, all VOC impacted soil was consolidated for treatment. Contaminated soil from the various areas at the site was excavated and hauled to the Garage Area, where it was and spread and compacted in place.

The DVE system consisted of 33 DVE wells divided into 25 shallow DVE wells, screened in the overburden, and 8 deep DVE wells, screened in the upper bedrock and overburden. Five existing pilot test wells were left in place and used for vapor extraction. The wells were distributed over three manifold lines to provide the greatest coverage over the area of contamination. After 10 months of operation, approximately 53 pounds of VOCs were removed by the DVE system, with SVE removing about 48 pounds and groundwater extraction removing about 5 pounds. The soil cleanup goals were achieved. VOCs extracted in the vapor phase were reduced from concentrations as high as 16 ppm to below 1 ppm (the soil cleanup goal). However, total VOCs concentrations in groundwater remained above the cleanup goals. According to Terra Vac, DVE was not intended to achieve groundwater remediation goals; rather the extraction and treatment of groundwater was necessary to target and remediate soil contamination located within the saturated zone. A pump and treat system is currently operating at the site to provide a long term migration control remedy for groundwater. The actual project cost was $1.5 million, or $170/cy (based on 9,000 cy treated).

Frozen Soil Barrier at Oak Ridge National Laboratory, Oak Ridge, Tennessee

Site Name:
Oak Ridge National Laboratory

Location:
Oak Ridge, Tennessee

Period of Operation:
September 1996 to September 1998

Cleanup Authority:
NRC

Purpose/Significance of Application:
Demonstrate frozen soil barrier for containment of contaminated surface impoundment

Cleanup Type:
Field demonstration

Contaminants:
Radionuclides
- Initial concentrations in sediment included strontium 90 - 75 Curies (Ci) and cesium 137 - 16 Ci

Waste Source:
Nuclear processing operations

Contacts:

Technology Vendor:
Edward Yarmak
Chief Engineer
Arctic Foundations Inc.
(907) 562-2741

Technical Contacts:
Elizabeth Phillips, Principal Investigator, DOE Oak Ridge
(423) 241-6172

Michael Harper, Co-Principal Investigator, Bechtel Jacobs Company LLC
(423) 574-7299

Steven Rock, EPA SITE
(513) 569-7149

DOE Contact:
Scott McMullin, DOE Savannah River
(803) 725-5608

Technology:
Frozen Soil Barrier
- The demonstration used an array of 50 sealed thermocouples installed around the perimeter of the impoundment, on 6 ft centers to a depth of approximately 30 ft bgs
- The thermocouples were fabricated from 6 inch schedule 40 steel pipe, and used carbon dioxide as a working fluid, with an above-ground refrigeration system, to freeze the soil
- The refrigeration system used R-404A, and thermal expansion valves, to control the amount of freezing
- The frozen soil barrier was established in 18 wks, had a length of 300 linear ft, depth of 30 ft, thickness of 12 ft, frozen soil volume of 108,000 ft^3, and contained a volume of 168,750 ft^3
- A two-part polyurea coating was spray applied over a non-woven geotextile fabric to prevent surface water from entering the isolated area
- The system was operated first in a freeze-down phase, where the frozen soil barrier was created; subsequent operation was in maintenance phase

Type/Quantity of Media Treated:
Soil, Sediment, Groundwater
- Depth to groundwater is 2 to 9 ft bgs
- Groundwater discharges to surface water at several locations around the impoundment
- Complex hydrology due to presence of fractured bedrock

Regulatory Requirements/Cleanup Goals:
- Evaluate performance of the barrier for isolating and containing contaminants
- No specific cleanup goals were identified

Results:
- Performance was evaluated based on groundwater level monitoring, dye tracer studies, and operation tests
- Groundwater level monitoring and dye tracer studies (eosine and phloxine dies) showed hydraulic isolation of the impoundment
- A 7-day loss of power test showed that the barrier maintained its integrity during a power outage

Costs:
- The actual cost for the demonstration was $1,809,000, consisting of $43,000 for site infrastructure, surveys, and maintenance; $1,253,000 for system design, fabrication, procurement, installation, and start-up; $274,000 for ORNL site support; and $239,000 for barrier verification
- A review of projected costs for frozen soil barriers to grouted barriers showed that frozen soil is less costly for initial installation and operation, with a break-even point of 8 to 9 yrs

Description:
The demonstration site is a former unlined, earthen impoundment used from 1958 through 1961 for retention/settling of liquid radioactive wastes generated from operation of a Homogeneous Reactor Experiment (HRE) at DOE's Oak Ridge facility. The impoundment was 75 ft long by 80 ft wide by 10 ft deep, with a capacity of approximately 310,000 gallons. In 1970, the impoundment was backfilled with local soils, covered with 8 inches of crushed stone, and capped with asphalt. A 1986 study found that sediments buried in the impoundment contained strontium 90 and cesium 137, and that groundwater that moved through this area transported contaminants to surrounding locations, including surface waters.

For the demonstration, a frozen soil barrier was constructed using thermocouple technology. The barrier had a length of 300 linear ft, depth of 30 ft, thickness of 12 ft, frozen soil volume of 108,000 ft^3, and contained a volume of 168,750 ft^3. Groundwater level monitoring and dye tracer studies showed that the barrier provided for hydraulic isolation of the impoundment, and a 7-day loss of power test showed that the barrier maintained its integrity during this time. A cost analysis comparing projected costs for frozen soil barriers to grouted barriers showed that frozen soil barriers are less costly for initial installation and operation, with a break-even point of 8 to 9 years.

Horizontal Wells Demonstrated at U.S. DOE's Savannah River Site and Sandia National Laboratory

Site Name:
U.S. DOE's Savannah River Site (SRS) and Sandia National Laboratory; Other Sites (report focuses on use at SRS)

Location:
Aiken, SC, and Albuquerque, NM

Period of Operation:
1988 - 1993

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstrate use of horizontal wells to treat groundwater at multiple sites and locations

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated solvents

Waste Source:
Multiple sources, including leaks of solvents

Contacts:

Technical Contacts:
Dawn Kaback
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(303) 297-0180 ext. 111
E-mail: dsdaback@csn.net

Management Contacts:
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grover.chamberlain@em.doe.gov

James A. Wright
DOE SRS
(803) 725-5608
E-mail: wrightjamesb@srs.gov

Technology:
Pump and Treat (report focuses on installation of horizontal wells above and below water table)

- Four different systems were used for directional drilling and horizontal well installation
- A short radius petroleum industry technology was used to install wells at 65 ft bgs and 150-175 ft bgs; these wells were constructed of steel
- A modified petroleum industry technology was used to install two comparable wells; these wells were constructed of HDPE
- A mini-rig utility industry/compactional tool drilling technology was used to install a well at 35-40 ft bgs; this well was constructed of fiberglass
- A mini-rig utility industry technology was used to install two wells at 100 ft bgs; these wells were constructed of PVC

Type/Quantity of Media Treated:
Groundwater (in situ)

- Geology consists of 200 ft of alternating units of permeable sands with low fines; water table is 120 ft bgs

Regulatory Requirements/Cleanup Goals:

- Test the feasibility of installing horizontal wells in unconsolidated sediments using directional drilling technology

Results:

- Directional drilling technology was used to install a total of seven wells (steel, stainless steel, PVC, HDPE, and fiberglass) to depths of 35 - 175 ft bgs, with horizontal screen sections ranging from 150 - 400 ft
- The wells were used to demonstrate in situ air stripping, in situ bioremediation, and thermally enhanced soil vapor extraction; four of the wells were later integrated in a vapor extraction remediation system

Costs:

- Costs for horizontal wells vary widely based on drilling method and size of rig, type of drilling tool, drilling fluid, guidance system, vertical depth, total well length, site geology, well materials, and number of personnel on site
- 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)
- Estimated capital costs for horizontal wells were comparable to the capital cost of five vertical wells; O&M costs for the one horizontal well were less than one-third of the O&M costs for five vertical wells

Horizontal Wells Demonstrated at U.S. DOE's Savannah River Site and Sandia National Laboratory

Description:
This report describes the installation and use of horizontal wells at several DOE sites, including Savannah River Site (SRS) and Sandia National Laboratories. At SRS, seven wells were installed at depths of 35 - 175 ft bgs, with horizontal screen sections ranging from 150 - 400 ft, and using the following materials: steel, stainless steel, PVC, HDPE, and fiberglass. The wells were used to demonstrate in situ air stripping, in situ bioremediation, and thermally enhanced soil vapor extraction; four of the wells were later integrated in a vapor extraction correction action. The SRS demonstration identified two important factors for consideration during design of horizontal wells: (1) trips in and out of the well bore should be minimized; and (2) well materials should be adequately flexible to negotiate curves.

At Sandia, several pieces of commercial machinery were tested and evaluated, including the water-assisted Jet Trac Boring System, the air-assisted True Trac Boring System, the P-80 rod pusher, and the Pierce Arrow pneumatic hammer tool. Based on the results from initial testing of these machines, construction was begun on a prototype machine, the X-810.

In Situ Chemical Oxi-Cleanse Process at the Naval Air Station Pensacola Florida, Operable Unit 10, Pensacola, Florida

Site Name:
Naval Air Station Pensacola Florida, Operable Unit 10

Location:
Pensacola, Florida

Period of Operation:
November 1998 to May 1999

Cleanup Authority:
RCRA Corrective Action

Purpose/Significance of Application:
Field demonstration of in situ chemical oxidation using Fenton's reagent to treat chlorinated solvents

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents
- TCE primary target for demonstration
- Maximum concentration of TCE 3,600 ug/L

Waste Source:
Unlined sludge drying bed

Contacts:

Vendors:
Mattehew Dingens
Geo-Cleanse International, Inc.
4 Mark Road, Suite D
Kenilworth, NJ 07033
Telephone: (908) 206-1250
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Technology:
In-Situ Chemical Oxidation using Fenton's Reagent
- Geo-Cleanse's patented process for in situ chemical oxidation conducted in two phases
- Fenton's reagent - hydrogen peroxide (50%) and an equivalent volume of ferrous iron catalyst
- Phase I injected 4,089 gallons of hydrogen peroxide and similar volumes of reagents through 14 injection wells at a depth of 10-40 ft bgs
- Phase 2 injected 6,038 gallons of hydrogen peroxide and similar volumes of reagent through 10 injection wells (9 old, 1 new), totaling 10,127 gallons; phosphoric acid was added to the reagent mix to stabilize the hydrogen peroxide
- Operating parameters included injection rate of 0.25 - 3 gpm, injection pressure of 5 - 110 psig, pH <8, and CO_2 evolution of 5% - >25%

Type/Quantity of Media Treated:
Groundwater
- 16,500 gallons of groundwater in the source area
- Depth to groundwater 0-4 ft; contaminants detected in groundwater 35-45 ft bgs
- Soil classified as fine to medium quartz sand
- Properties included porosity >15%; pH 3-6; hydraulic conductivity 2-44 ft/day; dissolved iron >500 mg/L

Regulatory Requirements/Cleanup Goals:
- Evaluate effectiveness of in situ chemical oxidation in treating chlorinated solvents
- No specific cleanup goals were identified

In Situ Chemical Oxi-Cleanse Process at the Naval Air Station Pensacola Florida, Operable Unit 10, Pensacola, Florida

Results:

- Phase I reduced TCE concentrations from as high as 3,600 ug/L to 485 ug/L in source area well
- This was considered insufficient reduction; Phase I performance was attributed to elevated concentrations of ferrous iron in the treatment area, likely due to a historic spill of sulfuric acid
- Phase II reduced TCE concentrations from 460 ug/L to <5 ug/L in source area well

Costs:

- Actual costs for this demonstration, reported by Geo-Cleanse, were $178,338, consisting of $97,018 for capital and $81,320 for O&M; these costs do not include electrical power or water supply, which were provided by NAS Pensacola

Description:

Naval Air Station (NAS) Pensacola is a 5,800-acre naval facility located in the western portion of the Florida panhandle. Operable Unit (OU) 10, is located on 26 acres of Magazine Point Peninsula in the northeast corner of the NAS, was the site of the former Industrial Wastewater Treatment Plant (IWWTP). The IWWTP treated wastewater from operations such as painting and electroplating, as well as organic solvents and acids, and included an unlined sludge drying bed. A groundwater recovery system had been operated for more than 10 years under a RCRA corrective action program to control migration of contaminated groundwater. In situ chemical oxidation using the Geo-Cleanse patented process was evaluated for its ability to reduce concentrations of chlorinated solvents in the source area, such that natural attenuation would be an effective remedy for down-gradient groundwater.

The Geo-Cleanse process used Fenton's reagent (hydrogen peroxide (50%) and an equivalent volume of ferrous iron catalyst) and was conducted in two phases at OU-10. A total of 10,127 gallons of hydrogen peroxide and similar volumes of reagents were injected under pressure through 15 wells at a depth of 10-40 ft bgs. Over the two phases, the concentration of TCE was reduced from 3,600 ug/L to <5 ug/L, as measured in a source area monitoring well. Elevated concentrations of ferrous iron in the groundwater, due to a historic sulfuric acid spill, limited the effectiveness of the first phase of injections. In the second phase, phosphoric acid was added to the reagent mix to help stabilize the hydrogen peroxide in the presence of elevated ferrous iron concentrations. The actual costs for the demonstration were $178,338, and additional injections were not planned for this site.

In Situ Chemical Oxidation Using Fenton's Reagent at Naval Submarine Base Kings Bay, Site 11, Camden County, Georgia

Site Name:
Naval Submarine Base Kings Bay, Site 11

Location:
Camden County, GA

Period of Operation:
November 1998 through August 1999 (Phase 1 and 2)

Cleanup Authority:
RCRA Corrective Action

Purpose/Significance of Application:
Use of Fenton's Reagent to remediate chlorinated solvents in groundwater

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents
- PCE source was 120 feet long by 40 feet wide; 30 to 40 foot horizon below ground surface (bgs); PCE concentrations in landfill source area detected as high as 8,500 µg/L
- TCE, DCE, and VC detected at concentrations of more than 9,000 µg/L in groundwater within the landfill source area
- Because PCE concentrations were as much as 5 percent (%) of the pure solubility phase, the presence of dense non-phase aqueous liquids (DNAPL) was inferred

Waste Source:
Leaks from a landfill

Contacts:

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State Contact:
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Navy Contact:
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Technology:
In Situ Chemical Oxidation; Fenton's reagent
- Geo-Cleanse's patented process for in situ chemical oxidation using Fenton's reagent
- Fenton's reagent - hydrogen peroxide (50%) and an equivalent volume of ferrous iron catalyst were delivered via injection to the subsurface
- Total of 44 injectors - 23 for Phase 1, including deep (42 ft bgs) and shallow (32 ft bgs) injectors; 21 injectors added for Phase 2, including deep (40 ft bgs) and shallow (35 ft bgs) injectors
- Phase 1 - two injections of Fenton's reagent into the subsurface, totaling 12,045 gallons (8,257 gallons November 2-21, 1998; 3,788 gallons February 8-14, 1999) of solution were injected.
- Phase 2 - two injections of Fenton's reagent into the subsurface, totaling 11,247 gallons (8,283 gallons June 3-11, 1999; 2,964 gallons July 12-15, 1999)

Type/Quantity of Media Treated:
Groundwater
- Estimated volume of groundwater treated during the Phase 1was 78,989 gallons (based on a treatment volume of 1,778 cubic yards and a porosity of 22%)
- Information on volume of groundwater treated during Phase 2 was not provided

Regulatory Requirements/Cleanup Goals:
- Cleanup goal for the RCRA corrective action at Site 11 was established by the state at 100 µg/L for total chlorinated aliphatic compounds (CACs), defined as the sum of PCE, TCE, cis-1,2 DCE, and VC concentrations in groundwater

In Situ Chemical Oxidation Using Fenton's Reagent at Naval Submarine Base Kings Bay, Site 11, Camden County, Georgia

Results:

- Phase 1 - after first injection, total CAC concentrations were reduced to below the cleanup goal in five of the seven monitoring wells, including one well located within the source area where concentrations had been reduced by >97%. However, total CAC concentrations remained above the cleanup goal in two downgradient monitoring wells; after second injection, total CAC concentration remained at or above the cleanup goal in the two downgradient wells and were found to have increased in other wells. As a result, a second phase of treatment was performed
- Phase 2 - after the first injection, total CAC concentrations were reduced to below the cleanup goal in all but one downgradient monitoring well; however, concentrations increased above the cleanup goal in two downgradient injectors. After the second injection, total CAC concentrations were reduced to below the cleanup goal in the downgradient injectors and remained below the cleanup goal in all wells except for the one downgradient well (total CAC concentration was primarily DCE)
- Sample results from August 1999 showed elevated concentrations of total CACs in one injector located to the east of the area of concern. The Navy has determined that there is a previously unknown source of contamination in this area and is addressing the cleanup of the area separate from the Site 11 area of concern. Data on this cleanup were not available at the time of this report

Costs:

- Total proposed cost for application of in situ chemical oxidation of Fenton's reagent using the Geo-Cleanse process was approximately $223,000 for Phase 1, including costs for reagents, mobilization, onsite treatment time, injection and monitoring equipment, documentation, and injector construction oversight and materials
- No additional cost data were provided

Description:

Naval Submarine Base (NSB) Kings Bay, 16,000 acre facility in Camden County, GA, is the U.S. Atlantic Fleet home port to the next generation of ballistic submarines, and maintains and operates administration and personnel support facilities. Site 11 is the location of a former 25-acre landfill at NSB Kings Bay, known as the Old Camden County landfill, that was operated by the county during the mid-1970s to 1980. A variety of wastes from the local Kings Bay community and the Navy were disposed of in the landfill, including solvents and municipal waste. Site investigations found the groundwater in the area to be contaminated with PCE, as well as TCE, DCE, and VC. On March 18, 1994, NSB Kings Bay entered into a Corrective Action Consent Order with the Georgia Environmental Protection Division to address prior releases of hazardous constituents from Site 11. The Navy selected *in situ* chemical oxidation using Fenton's reagent for this site based on its successful use by the U.S. Department of Energy (DOE) in remediating chlorinated solvent contaminated groundwater at the Savannah River site. The Navy's approach to the cleanup of Site 11 was to use *in situ* chemical oxidation to reduce groundwater contaminant concentrations in the source area followed by natural attenuation to address residual contamination.

For the remeditation of Site 11, the Geo-Cleanse® process, a patented in situ chemical oxidation technology using Fenton's reagent, was used. The Fenton's reagent consisted of hydrogen peroxide (50%) and an equivalent volume of ferrous iron catalyst that were injected into the subsurface under pressure. The remediation was performed in two phases. For Phase 1, 23 injectors were installed in and around the area of concern and there were two injections of Fenton's reagent into the subsurface, totaling 12,045 gallons. During Phase 2, the system was expanded to add 21 injectors and there were two injections of Fenton's reagent into the subsurface, totaling 11,247 gallons. After two phases of treatment using the Geo-Cleanse® process, total CAC concentrations had been reduced to below the cleanup goal of 100 ug/L in all but one well located downgradient of the area of concern. The total CAC concentrations in this well were primarily DCE. The first phase of treatment (two injections) reduced total CAC concentrations to below the cleanup goal in five of the seven monitoring wells, including a reduction of >97% in the well located within the source area. Cost data provided by Geo-Cleanse indicated that the proposed cost for application of in situ chemical oxidation of Fenton's reagent was approximately $223,000 for Phase 1. No additional cost data were available.

In August 1999, elevated concentrations of total CACs concentrations were found in an injector located to the east of the area of concern, indicating the presence of an additional contamination source area in the shallow soil. The soil in this area has been excavated and the Navy is planning to use chemical oxidation to polish the groundwater in this area.

Six Phase Heating at the Skokie, Illinois Site

Site Name:
Confidential Manufacturing Facility

Location:
Skokie, Illinois

Period of Operation:
June 4, 1998 to April 30, 1999

Cleanup Authority:
State Voluntary Cleanup

Purpose/Significance of Application:
Use of SPH to remediate chlorinated solvents in soil and groundwater

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents

- Primary contaminants included TCE, TCA, and DCE
- Concentrations in groundwater at start of SPH remediation (June 1998) - TCE (130 mg/L maximum; 54.4 mg/L average), TCA (150 mg/L maximum; 52.3 mg/L average) and DCE (160 mg/L maximum; 37.6 mg/L average)
- DNAPL present

Waste Source:
Leaks from spill contaminant systems and underground storage tanks

Contacts:

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EPA Contact:
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PRP Oversight Contractor:
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ENSR
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Technology:
Six-Phase Heating™ (electrical resistive heating combined with soil vapor extraction)

- Initial network of 107 electrodes (85 beneath the floor of a warehouse building) operated from June to November 1998; 78 electrodes added (185 total) and operated from December 1998 to April 1999 to treat additional area of contamination
- Electrodes designed to be electrically conductive throughout a depth interval of 11 to 21 feet bgs and to increase the subsurface temperature in the depth interval of 5 to 24 feet bgs to the boiling point of water
- Electrical power input - 13.8 kV local service at 1250 kW; 1,775 megawatt hours (MW-hrs.) consumed from June 4 to November 20, 1998; information not provided for Dec. 1998/Jan. 1999 through May 1999
- Temperature - 100 °C; operating pressure/vacuum - 7.5 inches of mercury (Hg)
- Network of 37 soil vapor extraction wells, screened to 5 feet bgs, were used to capture vapors
- Off-gas was condensed and sent through an air stripper prior to discharge to the atmosphere

Type/Quantity of Media Treated:
Soil and groundwater

- 23,100 cubic yards treated from June to November 1998
- Additional 11,500 cubic yards treated from December 1998 to April 1999
- Soil at site - heterogeneous silty sands with clay lenses to 18 feet bgs (hydraulic conductivity -10^{-4} to 10^{-5} cm/sec); underlain by dense clay till aquitard (hydraulic conductivity -10^{-8} cm/sec)
- Depth to groundwater- 7 feet bgs

Six Phase Heating at the Skokie, Illinois Site

Regulatory Requirements/Cleanup Goals:

- Tier III cleanup criteria for groundwater; developed by ENSR and approved by Illinois EPA as the cleanup goals for the site
- Tier III goals were TCE (17.5 mg/L); TCA (8.85 mg/L); and DCE (35.5 mg/L)
- No criteria established for soil

Results:

Results for the remediation of the initial 23,000 cubic yards of contamination:

- By December 1998 (six months of operation), theTier III cleanup goals were achieved for TCE, TCA, and DCE in all wells in the initial area of contamination
- During this time, average groundwater concentrations were reduced by more than 99% for TCE (54.4 mg/L to 0.4 mg/L); more than 99% for TCA (52.3 mg/L to 0.2 mg/L), and more than 97% for DCE (37.6 mg/L to 0.8 mg/L)

Results for the remediation of the additional 11,000 cubic yards of contamination:

- By April 1999 (five months of operation), theTier III cleanup goals were achieved for TCE, TCA, and DCE in all wells in the additional area of contamination
- During this time, average groundwater concentrations were reduced by more than 96% for TCE (4.16 mg/L to 0.15 mg/L); more than 92% for TCA (14 mg/L to 1 mg/L); and more than 90% for DCE (2.39 mg/L to 0.24 mg/L)

Costs:

- Cost data were provided on a unit cost basis; total project cost data were not provided
- The unit cost for this technology of $32 per cubic yard is based on a calculated treatment volume of 23,100 cubic yards, or a treatment area of 26,000 square ft and a depth of 24 ft bgs
- The unit cost for the treatment from December 1998 through May 1999 also was $32 per cubic yard, based on a calculated treatment volume of 11,500 cubic yards

Description:

The Skokie site is a former electronics manufacturing facility located in Skokie, Illinois. From 1958 to 1988, manufacturing operations included machining and electroplating. Soil and groundwater at the site was found to be contaminated with solvents (TCE and TCA), including large pools of dense nonaqueous phase liquids (DNAPL). The site is being remediated under Illinois' voluntary Site Remediation Program. From 1991 to 1998, steam injection combined with groundwater and vapor extraction reduced the area of contamination from about 115,000 square feet to about 23,000 square feet. As of early 1998, the remaining area to be remediated represented four source locations where manmade subsurface features limited the effectiveness of the previously used steam-based remediation system. To complete the remediation, the site owner selected Six-Phase Heating™ (SPH).

The SPH process operated at the Skokie site from June 4, 1998 to November 20, 1998 to remediate the initial estimated 23,000 cubic yards of contaminated soil and groundwater. Based on the results of sampling conducted in December 1998 that indicated there was a potential for vinyl chloride to be produced outside the initial treatment area at levels in excess of the cleanup levels, a decision was made to expand the SPH system to cover an additional 11,500 cubic yard treatment area. The SPH system restarted in December 1998 and operated until April 30, 1999 when cleanup goals were achieved in the additional area. The unit cost for this technology was $32 per cubic yard for the initial 23,000 cubic yards of contaminated soil and groundwater and also for the additional 11,500 cubic yards of contaminated media.

Hydrous Pyrolysis Oxidation/Dynamic Underground Stripping (HPO/DUS) at Visalia Superfund Site, CA

Site Name: Visalia Superfund Site (report also includes treatment at DOE Portsmouth Site, Piketon, OH)	**Location:** Visalia, CA
Period of Operation: June 1997 to mid-1999	**Cleanup Authority:** CERCLA ROD – 6/10/94
Purpose/Significance of Application: Use of HPO/DUS for treatment of large quantity of creosote in groundwater	**Cleanup Type:** Field demonstration
Contaminants: Semivolatiles – Halogenated and Nonhalogenated • Creosote and pentachlorophenol were the primary contaminants	**Waste Source:** Wood preservation operations
Contacts: **Site Contact:** Southern California Edison **Vendor:** Steam Tech Environmental Services **Technical Contact:** Robin Newmark Lawrence Livermore National Laboratory Telephone: (925) 423-3644 E-mail: newmark1@llnl.gov **EPA Contact:** Kathi Moore U.S. EPA Region 9 75 Hawthorne Street San Francisco, CA 94105 (415) 744-2221 **Other Contacts:** James Wright DOE SRS Telephone: (803) 725-5608 E-mail: jamesb.wright@srs.gov Kathy Kauffman LLNL Telephone: (925) 422-2646	**Technology:** Hydrous Pyrolysis Oxidation/Dynamic Underground Stripping • DUS involved continuous injection of steam and air into permeable zones over a 5 month period to create a steam front, which swept contaminants from the injection wells toward extraction wells; when the steam front collapsed, groundwater reentered the treatment zone and the steam/vacuum extraction cycle was repeated in a process called "huff and puff" • System used 11 injection and 8 extraction wells; steam and air were injected to 80 - 100 ft bgs in paired wells; average temperature was 60ºC (maximum 140ºC), with groundwater extracted at 350 - 400 gpm • Extracted vapors initially were treated with carbon; however, because of the expense of the carbon, it was replaced with treatment in steam boilers • Extracted groundwater was treated with filtration and discharged to a POTW • HPO occurred after the steam and air injection stopped, when groundwater returned to the heated zone and mixed with oxygen; contaminants were rapidly oxidized in this environment • Underground mapping was performed using 29 electrical resistance tomography (ERT) wells and thermocouples to track the steam fronts and heated areas
	Type/Quantity of Media Treated: Groundwater • Three distinct water-bearing zones are present; shallow aquifers from 35 to 75 ft bgs, an intermediate aquifer from 75 to 105 ft bgs, and a deep aquifer below 120 ft bgs; the HPO/DUS system targeted the intermediate aquifer
Regulatory Requirements/Cleanup Goals: • Evaluate the performance of DUS/HPO for removing creosote	

Hydrous Pyrolysis Oxidation/Dynamic Underground Stripping (HPO/DUS) at Visalia Superfund Site, CA

Results:

- During 25 months of operation, a total of 1,130,000 lbs (141,000 gals) of creosote were removed or treated (10,400 lbs/wk)
- Approximately 50% of the contaminants were removed in free phase, 16% as vapors, 16% in an aqueous phase, and 17% destroyed by HPO in situ
- Monitoring the progress of the heating fronts showed that all the aquifer was treated

Costs:

- A comparison of projected costs for use of HPO/DUS and pump and treat at Visalia showed that HPO/DUS would have larger capital and annual O&M costs, but would be operated for less years, than pump and treat; projected unit costs were \$39/yd^3 for HPO/DUS and \$110/yd^3 for pump and treat
- Key factors affecting the cost analysis include the groundwater extraction capacity and size of plume

Description:

Since the 1920's, the four-acre Visalia Poleyard was the site of a wood preservation treatment plant for power poles. Poles were dipped into creosote, a pentachlorophenol compound, or both. Soil and groundwater to 100 ft bgs were contaminated with creosote, pentachlorophenol, and diesel fuel. A pump and treat system was installed in 1975 and several years later a slurry wall was constructed to contain the plume at its leading edge.

A field demonstration of Hydrous Pyrolysis Oxidation/Dynamic Underground Stripping (HPO/DUS) was conducted at Visalia over a 25-month period. HPO/DUS is a combination of technologies including steam and air injection, vapor extraction, pump and treat, and electrical resistance tomography. The system used at Visalia consisted of 11 injection and 8 extraction wells; steam and air were injected to 80 - 100 ft bgs in paired wells. Groundwater was extracted at 350-400 gpm. During the 25 months of operation, a total of 1,130,000 lbs (141,000 gals) of creosote were removed or treated (10,400 lbs/wk). Approximately 50% of the contaminants were removed in free phase, 16% as vapors, 16% in an aqueous phase, and 17% treated by HPO in situ.

Intrinsic Remediation at AOCs 43G and 43J, Fort Devens, Massachusetts

Site Name:
Areas of Concern (AOCs) 43G and 43J

Location:
Fort Devens, Massachusetts

Period of Operation:
Intrinsic remediation assessment (IRA) - 3/97 to 6/99
Long-term monitoring - 12/99 to 12/11 (AOC 43G) and 12/04 (AOC 43J). End dates are estimated.

Cleanup Authority:
CERCLA and State
Record of Decision (ROD) signed on October 17, 1996

Purpose/Significance of Application:
This project demonstrates that intrinsic remediation is a viable treatment alternative at sites contaminated with BTEX.

Cleanup Type:
Full scale

Contaminants:
Organic Compounds
- Volatiles (nonhalogenated)
- BTEX (benzene, toluene, ethylbenzene, and xylene)
- Maximum benzene concentrations:
  - 2,000 mg/L at AOC 43G
  - 300 mg/L at AOC 43J

Waste Source:
Leaks and spills from former gasoline and waste oil USTs.

Contacts:

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Technology:
Intrinsic Remediation
- Remediation approach requires a demonstration, through intensive site characterization, that natural biological processes are destroying contaminants in situ and that the site will reach specified remediation goals within 30 years
- The demonstration includes:
  - Observation of a stable or decreasing contaminant plume over time
  - Correlation of contaminant plumes with electron acceptor distribution
  - Modeling studies that indicate attenuation due to processes other than dispersion, volatilization, and sorption
- Eight quarterly sampling rounds were conducted to accumulate the data necessary for the remediation demonstration
- Annual long-term monitoring is required to confirm that adequate remediation is occurring

Type/Quantity of Media Treated:
- The contaminant plume at AOC 43G extends 320 feet downgradient from the source area and is 230 feet wide. The contaminant plume at AOC 43J extends 250 feet downgradient from the source area and is 190 feet wide. Plume dimensions were calculated based on groundwater concentrations above the maximum contaminant level (MCL) for benzene in March 1997
- The aquifer is approximately 5 feet thick at AOC 43G and 10 feet thick at AOC 43J
- Free product has been detected
- Electron acceptors are present in the groundwater at varying levels

Intrinsic Remediation at AOCs 43G and 43J, Fort Devens, Massachusetts

Regulatory Requirements/Cleanup Goals:

- The ROD established the preliminary remediation goals (PRGs) for AOCs 43G and 43J that must be met within 30 years; most goals were based on MCLs.
- Property boundary performance standards for AOCs 43G and 43J were based on the PRGs and the Massachusetts Contingency Plan (MCP) GW-1 standards for extractable and volatile petroleum hydrocarbons (EPH/VPH)

Results:

- The results of the Mann-Kendall statistical trend analyses on BTEX compounds at both sites indicated that groundwater concentrations exhibit a statistically significant decreasing trend
- At both sites, there is significant evidence of the utilization of electron acceptors and the appearance of degradation products, suggesting that contaminants are being biologically degraded and not just physically diluted or dispersed
- Modeling indicates that the contaminant plumes at both sites will be reduced below the applicable MCLs between 8 and 15 years after the ROD was signed
- Fate and transport modeling demonstrated that it was unlikely that the BTEX plumes would move off of Army property

Costs:

- The total cost for the IRA was $671,642
- The anticipated long-term monitoring and reporting costs are $50,000 per year
- The number of wells sampled is a significant cost element because it effects the duration of field sampling events, analytical expenses, and the effort involved with tracking and assessing data

Description:

AOCs 43G and 43J are two former gasoline stations operated at Fort Devens. These sites were also used for motor pool operations during World War II. BTEX and TPH contamination in soil and groundwater at these sites is consistent with the historical use of the areas. The Army determined that intrinsic remediation was the most appropriate remedy for the contamination at both sites. The remedy consists of intrinsic remediation, IRA data collection and groundwater modeling, long-term groundwater monitoring and annual reporting, and five-year site reviews

The IRAs for AOCs 43G and 43J demonstrated that intrinsic remediation is working and that the Army will not need to initiate additional cleanup actions. Specifically, modeling indicates that the concentrations of the contaminants of concern will be below groundwater cleanup levels in less than 30 years and that they will not migrate off of Army property

Monitored Natural Attenuation at Keesler Air Force Base, Mississippi

Site Name:
Keesler Air Force Base (AFB), Base Exchange Service Station, Area of Concern – A (ST-06)

Location:
Biloxi, Mississippi

Period of Operation:
September 1997 to April 1999

Cleanup Authority:
EPA Region 4 and Mississippi DEQ

Purpose/Significance of Application:
Monitored natural attenuation for a gasoline contaminated site

Cleanup Type:
UST cleanup

Contaminants:
BTEX, Lead

- Soil concentrations measured as high as 166 mg/kg for BTEX and 8.7 mg/kg for lead
- Groundwater concentrations measured as high as 22,400 ug/L for BTEX and 21 ug/L for lead

Waste Source:
Gasoline USTs and associated piping

Contacts:

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Technology:
Monitored Natural Attenuation

- Bioventing and density-driven convection in-well aeration were used previously as source control measures
- Monitoring of 9 groundwater wells planned for five years
- Samples will be analyzed for aromatic volatile organics and geochemical parameters

Type/Quantity of Media Treated:
Soil, groundwater, and soil gas

- Source area plus dissolved plume covers approximately 4.0 acres
  - Fine- to medium-grained sand to 20 ft bgs, underlain by a clay layer of unknown thickness
  - Groundwater present at 5 to 9 ft bgs
  - Average hydraulic conductivity of sand zone is 40 ft/day
  - Calculated horizontal groundwater flow velocity is 0.8 ft/day

Monitored Natural Attenuation at Keesler Air Force Base, Mississippi

Regulatory Requirements/Cleanup Goals:
- Cleanup levels for BTEX was 100 ppm for soil and 18 ppm for groundwater
- Risk-based screening levels for lead was identified as 400 ppm in soil and 15 ug/L in groundwater
- OSHA PELs were used as screening levels for BTEX in soil gas

Results:
- In February 1998, the only contaminant in soil to exceed the cleanup levels was BTEX (1 sample at 166 mg/kg); BTEX (1 sample at 22.4 mg/L) and lead (3 samples – 21, 21 and 16 ug/L) exceeded the cleanup levels in groundwater. Only lead in groundwater was identified as a chemical of potential concern for this site
- Data from 1988 to 1998 indicated substantial oscillation in dissolved BTEX concentrations at the plume core since May 1993, but that the total BTEX plume appears to have been relatively stable

Costs:
- The estimated O&M cost for long-term monitoring was identified as $15,000 per event

Description:
In 1987, 10 USTs were removed from the Keesler Air Force Base, in Biloxi, Mississippi. During the removals, there was evidence that one or more of the tanks had leaked, and site investigations found gasoline components in the soil and groundwater, including BTEX and lead. A bioventing system was installed in 1993 and operated for three years. A density-driven convection (DDC) in-well aeration system was installed in 1996 and operated at least through February 1998. Based on a RBCA analysis, the recommended final remedial action was monitored natural attenuation. The recommendation was based on the finding that the site contamination does not currently (and will not in the future) pose a significant risk to potential receptors, the dissolved plume is stable and degrading, and institutional controls can be maintained with a high level of confidence. The RBCA analysis showed that concentrations of target analytes in all sampled media do not exceed applicable MDEQ RBSLs or OSHA PELs, and that detected concentrations of total lead in groundwater do not pose a risk to potential receptors.

Geochemical data indicated that biodegradation of fuel hydrocarbons is occurring at the site, primarily via the anaerobic processes of sulfate reduction, nitrogen fixation, and methanogenesis. Previous and current source removal efforts have reduced hydrocarbon concentrations in vadose zone and saturated zone soils, and the current system does not have an adverse effect on the natural attenuation processes at the site. A long-term monitoring plan was negotiated with the MDEQ and USEPA Region 4 that included monitoring of nine wells for five years. Monitoring will occur quarterly for the first year and annually for the second through fifth years. The purpose of the monitoring is to verify the effectiveness of naturally-occurring remediation processes at limiting plume migration and reducing dissolved contaminant concentrations.

Monitored Natural Attenuation at Kelly Air Force Base , Former Building 2093 Gas Station, Texas

Site Name: Kelly Air Force Base (AFB), Former Building 2093 Gas Station	**Location:** Kelly AFB, Texas
Period of Operation: July 1997 to July 1998	**Cleanup Authority:** Texas Natural Resource Conservation Commission Petroleum Storage Tank Division
Purpose/Significance of Application: Monitored natural attenuation for a gasoline-contaminated site	**Cleanup Type:** UST cleanup
Contaminants: Gasoline constituents • BTEX concentrations in groundwater measured as high as 2,807 ug/L in November 1997	**Waste Source:** Leaking gasoline USTs and associated piping
Contacts: **Vendor:** John Hicks Parsons Engineering Science, Inc. 1700 Broadway, Suite 900 Denver, CO 80290 (303) 831-8100 john.hicks@parsons.com **Site Contact:** Jerry Arriaga SA-ALC/EMRO 301 Tinker Dr., Suite 2 Bldg. 301 Kelly AFB, TX 78241 (210) 925-1819 garriaga@emgate1.kelly.af.mil. **Air Force Contact:** Jim Gonzales AFCEE/ERT 3207 North Rd., Building 532 Brooks AFB, TX 78235-5363 (210) 536-4324 james.gonzales@hqafcee.brooks.af.mil. **State Contact**: Antonio Pena TNRCC P.O. Box 13087 Austin, TX, 78711-3087 (512) 239-2200 APENA@tnrcc.state.tx.us.	**Technology:** Monitored Natural Attenuation • Monitoring network not described
	Type/Quantity of Media Treated: Soil, groundwater, and soil gas • Source area plus dissolved plume covers 1.5 acres • The site is underlain by silty clay; with a distinct clay unit from 35 to 40 ft bgs • Groundwater occurs primarily in silt and possibly caliche seams that produce only small amounts of water; static groundwater levels range from 5 to 25 feet bgs, depending on location and season • Hydraulic conductivity of the silty clay unit is 0.2 to 0.5 ft/day based on slug tests, and the estimated horizontal groundwater flow velocity is 31 ft/year
Regulatory Requirements/Cleanup Goals: • TNRCC Plan A target concentrations for Category II aquifers, and TNRCC target concentrations for construction worker exposure are the cleanup goals for affected groundwater	

Monitored Natural Attenuation at Kelly Air Force Base , Former Building 2093 Gas Station, Texas

Results:
- Based on a Tier 1 screening, only the Plan A concentration for benzene of 0.0294 mg/L was exceeded, and benzene in groundwater and soil was identified as a contaminant of potential concern
- Fate and transport modeling using the analytical code BIOSCREEN indicated that the maximum migration distance of dissolved benzene from the source area will be approximately 300 ft, and that dissolved benzene concentrations will be below groundwater quality standards within 10 years
- Results of groundwater sampling events indicated that the dissolved contaminant plume is not increasing in areal extent, and that natural attenuation indicator parameters exhibit trends associated with a plume that is being naturally degraded.
- The site was identified as a candidate for immediate closure according to TNRCC guidance
- The Air Force will restrict use of the shallow groundwater at the site until all dissolved benzene concentrations decrease below TNRCC Plan A Category II criterion of 0.0294 mg/L
- Maximum-detected concentrations of BTEX in soil gas were compared to the chemical-specific OSHA 8-hour time-weighted average permissible exposure limits (PELs), and there were no exceedences

Costs:
Not provided

Description:
As a result of UST integrity testing in 1989, the former Building 2093 Gas Station at Kelly Air Force Base, in Texas, was found to be leaking, and the UST and associated piping were removed in 1991. Site investigations found BTEX contamination in the groundwater. A 1-year-long bioventing pilot test was concluded in January 1995; the test results indicated that site soils were not sufficiently permeable to enable use of this in situ source reduction technique. Later in 1995, the dispensing islands and remaining below-grade piping were removed, and 2,750 cubic yards of soil in the area of the former tank pad and dispensing islands were excavated. Based on a RBCA analysis, the TNRCC issued a no-further-action memorandum closing the site based on plume stability, the occurrence of natural attenuation of fuel residuals, and the conclusion that site contamination will not pose a significant risk to potential receptors.

In Situ Permeable Reactive Barriers for Contaminated Groundwater at Fry Canyon

Site Name:
Fry Canyon

Location:
Southeastern Utah

Period of Operation:
September 1997 - ongoing (performance data for first year of demonstration - September 1997 to September 1998)

Cleanup Authority:
Not applicable

Purpose/Significance of Application:
Field demonstration of three types of PRBs to treat uranium-contaminated groundwater

Cleanup Type:
Field demonstration

Contaminants:
Radionuclides (uranium) and metals
- Uranium concentrations in groundwater found at levels as high as 16,300 ug/L
- Iron and manganese concentrations found in groundwater at 90 ug/l and 180 ug/L, respectively

Waste Source:
Subsurface drainage from abandoned uranium ore mill ponds

Contacts:

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Technology:
Permeable Reactive Barriers (PRBs)
- Three types of PRBs demonstrated - phosphate (PO_4), zero valent iron (ZVI), and amorphous ferric oxyhydroxide (AFO)
- PRBs installed side-by-side and operated concurrently
- Funnel and gate design; each PRB was keyed, along with each of the impermeable funnels, into the bedrock (Cedar Mesa Sandstone formation) beneath the colluvial aquifer
- 1.5-foot layer of pea gravel on the upgradient side of the PRBs to facilitate uniform flow of groundwater into the PRBs
- “As built” volume of reactive material was: PO_4 - 67.2 ft^3; ZVI - 77.7 ft^3, and AFO - 67.2 ft^3
- Each PRB contains a total of 22 monitoring wells, configured in two parallel “rows” - Row 1 and Row 2
- Estimated range of groundwater velocity through PRBs - 0.2 - 2.5 ft/day

Type/Quantity of Media Treated:
Groundwater - 33,000 cubic feet (about 200,000 gallons)
- Depth to groundwater - 8 feet bgs
- Colluvial aquifer ranges in depth from 2-5 feet
- Groundwater flow rate - 0.2-2.5 ft/day
- Transmissivity - 10-200 ft/day
- Hydraulic conductivity - 55-85 ft/day

Regulatory Requirements/Cleanup Goals:
The objective of the demonstration project is to evaluate the use of three types of PRBs in controlling the migration of uranium and metals in groundwater

Results:
- Performance data were available for the first year (September 1997 to September 1998) of this ongoing demonstration
- The ZVI PRB showed the best removal rate of the three PRBs tested, removing more than 99.9% of the uranium from the groundwater
- The PO_4 PRB initially removed more than 99% of the uranium from the groundwater, with the removal rate decreasing to 60-70% in January 1998, then increasing to 92% as of September 1998. Available results from tracer tests indicated that there was no leakage from the ZVI PRB to the PO_4 PRB; rather, the increased efficiency in the PO_4 PRB is the result of anoxic conditions caused by the release of PO_4
- The AFO PRB had the lowest removal rate, consistently removing less than 90% of the uranium from the groundwater; with removal rates as low as 37% observed

In Situ Permeable Reactive Barriers for Contaminated Groundwater at Fry Canyon

Costs:

- The cost for the PRB demonstration included \$280,000 for site selection, characterization, and PRB material testing; \$148,000 for design of the PRBs; and \$246,000 for the installation of the PRBs
- O&M costs were reported as being relatively expensive because of the extensive monitoring performed for the demonstration compared to full-scale operation. Projected costs for full-scale O&M for a comparable site were estimated to be \$55,000-\$60,000 per year

Description:

Fry Canyon, located in southeastern Utah (approximately 60 miles west of Blanding, Utah), is the site of an abandoned uranium ore milling operation and copper leach operation. From 1957 to 1960, COG Minerals Corporation conducted uranium upgrading (concentrating) operations at the site, and from 1962 to 1968, the Besinare Company conducted copper leach operations. Waste from these operation, including tailings, were stored and disposed of at the site. The Utah Department of Health, Bureaus of Radiation Control and Solid and Hazardous Waste, conducted site visits to Fry Canyon in 1984 and 1986. Elevated levels of uranium were found in water samples from Fry Creek. The site was selected by the U.S. Environmental Protection Agency (EPA) in cooperation with the U.S. Geological Survey (USGS), the U.S. Department of Energy (DOE), BLM, and the Utah Department of Environmental Quality, for a field demonstration of PRBs to assess their performance in removing uranium from groundwater.

Prior to constructing the PRBs, extensive laboratory investigations were conducted to evaluate the various reactive materials for each type of PRB and to select the specific reactive materials for the Fry Canyon demonstration. Three types of PRBs were demonstrated - phosphate (PO_4), zero valent iron (ZVI), and amorphous ferric oxyhydroxide (AFO). The PRBs were constructed side-by-side to allow all three types of materials to be evaluated during the demonstration period. A funnel and gate design was used and each PRB was keyed into bedrock beneath the colluvial aquifer at the site. After one year of operation, the ZVI PRB showed the best performance, consistently removing more than 99% of the uranium from the groundwater. The next best performance was observed for the PO_4 PRB. While the removal rate for the PO_4 PRB varied throughout the year, decreasing to as low as 62%, as of September 1998, the uranium removal rate for the PO_4 PRB at the end of one year of operation was greater than 92%. The AFO PRB initially removed greater than 90% of the uranium from the groundwater, but dropped to as low as 37% after the first year of operation.

Several problems were encountered during installation of the PRBs. For example, a large bedrock nose was encountered that caused the PRBs to be rotated such that groundwater entered into the gate structures at an oblique angle rather than perpendicular, as designed. To prevent this problem for other applications, a more detailed view of the bedrock topography would be needed during site characterization. Full-scale cost considerations include potential lower costs for design and operation compared to the demonstration costs, which included three PRBs and a more extensive monitoring system than would be needed for a non-research application.

Permeable Reactive Wall Remediation of Chlorinated Hydrocarbons in Groundwater at Moffett Field Superfund Site

Site Name:
Naval Air Station, Moffett Field Superfund Site

Location:
Mountain View, CA

Period of Operation:
April 1996 - December 1997
(Monitoring data available June 1996 through December 1997)

Cleanup Authority:
Installation Restoration Program

Purpose/Significance of Application:
Field demonstration of PRB to remediate groundwater contaminated with chlorinated solvents

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents
- Groundwater contaminated with chlorinated volatile organic compounds (CVOCs) including TCE, cis-1,2-DCE, PCE, and 1,1-DCE; TCE is the most prevalent contaminant at the site
- CVOC plume, located in the near surface A aquifer, is more than 10,0000 feet long and about 5,000 feet wide
- TCE and PCE concentrations in the A aquifer reported above 20 mg/L and 0.5 mg/L, respectively

Waste Source:
Wastes from operations and waste management activities, including leaks from underground storage tanks, aboveground tanks, and sumps

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Technology:
Permeable Reactive Barrier (PRB)
- Funnel-and-gate system; pea gravel added to gate to help distribute groundwater flow through reactive cell
- PRB is 10 feet long (6 feet of reactive material) by 10 feet wide; installed at depth from +5 feet bgs to -14 feet bgs; keyed into low-permeability sediments (sand channel)
- Reactive material - iron (from Peerless Metal Products, Inc.); -8 to +40 mesh particle size range
- Groundwater monitoring well network includes wells within the PRB as well as upgradient and downgradient

Type/Quantity of Media Treated:
Groundwater
- The aquifer includes two units - A1 which is up to 20 feet thick and is overlain by a clayey surface layer of varying thickness; and A2 which is up to 20 feet thick and extends to 40 feet below mean sea level
- Aquifer contains multiple channels of sand and gravel; zone is not laterally homogenous due to the interbraided channel nature of the sediments
- Both units are contaminated; however, the pilot-scale PRB penetrates the A1 unit only
- A1 unit - hydraulic gradient ranges from 0.005 to 0.009; hydraulic conductivity ranges from 0.04 foot/day to 633 feet/day (due to lithographic variation); groundwater velocity ranges from 0.2 to 5.0 feet/day

Regulatory Requirements/Cleanup Goals:
- Groundwater cleanup goals are the MCLs for PCE (5 mg/L), TCE (5 mg/L), cis-1,2-DCE (70 mg/L), and vinyl chloride (2 mg/L), as measured in the effluent from the PRB

Permeable Reactive Wall Remediation of Chlorinated Hydrocarbons in Groundwater at Moffett Field Superfund Site

Results:

- The PRB monitored on a quarterly basis from June 1996 to October 1997 (five quarters total)
- By October 1997, TCE, PCE, DCE, and VC were reduced to below the MCLs in the effluent from the PRB
- Data from two wells located within the reactive cell (one upgradient; one downgradient) were used to analyze trends in TCE and DCE degradation:
  - TCE concentrations in both wells remained below the MCL every quarter except for June 1996; possible reasons for the elevated TCE levels in June 1996 included adsorption-desorption on the iron surfaces and residual contamination from construction activities attributed to the recent installation of the PRB (April 1996)
  - DCE concentrations in both wells remained below the MCL for all five quarters
  - Over the five quarters, TCE concentrations were relatively constant in both wells
  - There was wider variation in DCE concentrations between the two wells; lower DCE concentrations were observed in the downgradient well, indicating that DCE degraded more slowly than TCE in the reactive medium.

Costs:

- The total cost associated with the treatment of groundwater during the pilot-scale PRB demonstration was $802,375, including $652,375 in capital costs and $150,000 in O&M costs
- The projected capital cost for a full-scale PRB at Moffett Field was $4,910,942. O&M costs for a full-scale system were projected to be $72,278 in annual monitoring costs and $267,538 in barrier maintenance costs, incurred once every ten years, to replace part of the iron medium
- The projected full-scale costs assumed that the PRB would be constructed in two sections - the first section to capture and treat the groundwater; the second section, constructed downgradient from the leading edge of the plume to control further migration of the plume; both sections would extend to the base of the A2 aquifer zone, a depth of about 65 feet

Description:

The Naval Air Station, Moffett Field, located in Mountain View California, was selected by the U.S. Navy as part of the Installation Restoration Program for a field demonstration of a PRB. Groundwater at Moffett Field is contaminated with chlorinated solvents, and the site was placed on the National Priorities List in 1987. An area known as the West Side Plume, a chlorinated solvent plume (primarily TCE) located on the west side of Moffett Field, was used for the demonstration. Based on the results of laboratory testing, iron from Peerless Metal Powders was selected for the PRB.

The pilot-scale PRB, installed in April 1996, was a funnel-and-gate design, keyed into low-permeability sediments. The PRB was operated through October 1997, with groundwater monitored quarterly from June 1996 through October 1997 (five quarters total). By October 1997, TCE, PCE, DCE, and VC were reduced to below the cleanup goals in the effluent from the PRB. Additional data for TCE and DCE collected from wells located within the reactive cell showed that TCE and DCE concentrations within the PRB were generally below the MCLs, and that DCE degraded more slowly in the reactive cell than TCE. The projected cost for a full-scale PRB at Moffett Field was $4,910,942 in capital costs and $72,278 in annual monitoring costs. In addition, the projected O&M costs included $267,538 in barrier maintenance costs for iron medium replacement, incurred once every ten years.

Groundwater Extraction and a Permeable Reactive Treatment Cell at Tacony Warehouse, Philadelphia, Pennsylvania

Site Name:
Tacony Warehouse (TW)

Location:
Philadelphia, Pennsylvania

Period of Operation:
May 13, 1998 through 2001 (projected)

Cleanup Authority:
CERCLA and State
Record of Decision (ROD) signed on July 21, 1995

Purpose/Significance of Application:
This project demonstrates that an extraction well that is surrounded by permeable reactive media (iron filings) is a viable treatment alternative at sites contaminated with chlorinated solvents.

Cleanup Type:
Full scale

Contaminants:
Organic Compounds
- Volatiles (halogenated)
  Maximum concentrations: 4,214 mg/L PCE, 579 mg/L TCE, 2,800 mg/L cis-1,2-DCE, 64.6 mg/L trans-1,2-DCE, 2,000 mg/L vinyl chloride

Waste Source:
The source of chlorinated solvents in the groundwater is not known.

Contacts:

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Technology:
- Pump and treat using a permeable reactive treatment cell
- Three extraction wells are being used to remove groundwater at the site. The system extracts an average of 3 gallons per minute
- The Tacony Treatment Cell or TTC is located near the monitoring well with the highest VOC concentrations (MW-9). The TTC is four feet in diameter and is filled with 22 tons of zero-valent iron filings around a four-inch diameter extraction well. The thickness of the iron filings layer was calculated to provide a 10 hour detention time
- Zero-valent iron reacts with the chlorinated hydrocarbons to form less-chlorinated and non-chlorinated hydrocarbons
- EW-1 and EW-2 are six-inch extraction wells with no reactive media. They were located to influence the hydraulic capture zone
- Extracted groundwater is discharged to the City of Philadelphia sanitary sewer system

Type/Quantity of Media Treated:
- Before treatment began, an area in the vicinity of MW-9 was contaminated in addition to an area approximately 300 feet downgradient of MW-19
- During the first year of operation, approximately 1.8 million gallons were extracted from the aquifer beneath the site, of which 393,165 gallons were treated by the TTC
- The contaminated aquifer is between 8 and 35 feet below ground surface (bgs). The aquifer can be described as heterogeneous and anisotropic, with hydraulic conductivities ranging from 2.3 to 29.4 gal/day/ft^2

Regulatory Requirements/Cleanup Goals:
- PADEP established the groundwater remediation goal of achieving background levels, which are based on the analytical quantitation limits of EPA SW-846 Test Method 8240. The remediation targets are 5 mg/L for PCE, TCE, and DCE and 10 mg/L for vinyl chloride
- The City of Philadelphia does not allow water to be discharged to the sewer system at concentrations exceeding 2.13 mg/L of total toxic organics

Groundwater Extraction and a Permeable Reactive Treatment Cell at Tacony Warehouse, Philadelphia, Pennsylvania

Results:

- The TTC is demonstrating conversion of PCE and TCE to less-chlorinated hydrocarbons when compared to untreated groundwater at MW-9, which is located approximately 15 feet away. PCE and TCE were not detected at the TTC, however, intermediate reaction products (cis-1,2-DCE and vinyl chloride) were observed
- Three of the six target monitoring wells are meeting the remedial standards and a fourth well met the standards in April 1999 but exceeded these levels in June 1999
- The sewer discharge meets the City of Philadelphia limit on total toxic organics

Costs:

The total project cost was $607,336, which includes the capital costs ($416,777), one year of operation and maintenance ($16,880), and other related costs ($132,417)

Description:

The TW site is located on 14.2 acres of land adjacent to the Delaware River in northeast Philadelphia. The site was constructed and established as an armor plate assembly facility in 1943. The site was used for warehousing operations from the 1950s through 1992, when the site was vacated. During this time, there were several periods of inactivity and numerous changes in accountability for the site.

Site investigations at the TW site indicate that the groundwater in several areas is contaminated with chlorinated solvents and that soil contamination around MW-9 may be a potential ongoing source of contamination. Use of barriers constructed from zero-valent iron has been demonstrated to be an effective treatment method at other sites contaminated with chlorinates solvents. At TW, groundwater in the vicinity of MW-9 is drawn through a bed of iron filings surrounding an extraction well. As the groundwater passes through the bed, it is treated through reductive dehalogenation reactions. The treated water is combined with untreated groundwater from two other on-site extraction wells and is discharged to the city sanitary sewer.

Results from the first year of operation indicate that reductive dehalogenation reactions are occurring, but not to completion. Permeable reactive extraction wells are applicable for many sites, especially where contamination is migrating off-site. In these cases, the hydraulic control provided by pumping may be necessary or the installation of an interceptor wall may not be feasible.

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DEBRIS/SOLID MEDIA TREATMENT ABSTRACTS

Direct Chemical Oxidation at Lawrence Livermore National Laboratory
Livermore, California

Site Name:
Lawrence Livermore National Laboratory (LLNL)

Location:
Livermore, California

Period of Operation:
Not identified

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Pilot-scale demonstration of the DCO process to treat a variety of organic aqueous waste streams

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated solvents, PCBs, kerosene, explosives, ion exchange resins
- Solvents - TCE, PCE, methylene chloride, chloroform
- 2,4,6-TNT, triethylamine, ethylene gylcol

Waste Source:
LLNL waste streams or surrogates containing chlorinated solvents

Contacts:

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Technology:
Direct Chemical Oxidation (DCO)
- Nonthermal, low temperature, ambient pressure, aqueous-based technology used to oxidize organic compounds in hazardous and mixed waste streams to carbon dioxide and water
- Oxidizing agent - sodium or ammonium peroxydisulfide
- Five continuously stirred tank reactors (CSTRs) - pretreatment, feed, and three-stage oxidizer (15L each)
- Hydrolysis used a pretreatment step for highly volatile wastes - for demonstration, hydrolysis used in tests of PCB waste streams only
- Operating temperature - hydrolysis - ≤150°C; oxidation - 90°C
- Oxidation rate - about 200-kg (as carbon) per cubic meter of reactor per day
- Tests conducted on several types of waste streams including concentrated waste streams (2,4,6-TNT, kerosene, triethlyamine, Dowex - an ion exchange resin, ethylene glycol), kerosene(predominately dodecane), chlorinated solvents (PCE, TCE, methylene chloride, chloroform and a mix of PCE and chloroform), and low concentrations (45 ppm) of PCBs
- The tests included oxidation and destruction rates for concentrated waste streams; oxidation time profile for kerosene; oxidation of chlorinated solvents without hydrolysis pretreatment; and treatment of PCB waste both with and without hydrolysis pretreatment

Type/Quantity of Media Treated:
Waste streams from LLNL operations

Regulatory Requirements/Cleanup Goals:
- The purpose of the demonstration was to evaluate the DCO process on a variety of organic waste streams, including concentrated waste streams, under varying conditions
- No specific goals were established for the demonstration

Direct Chemical Oxidation at Lawrence Livermore National Laboratory Livermore, California

Results:

- Concentrated waste streams - the oxidation rate (based on Ka of 0.02-0.04 min^{-1} and input concentration of 5N oxidant) and the destruction rate were calculated for the concentrated waste streams; the oxidation rate was considered to be a rough estimate for CSTR scaling; oxidation rates ranged from 132 kg/m^3/day (TNT and Dowex) to 432 kg/m^3/day (ethylene glycol); destruction rates ranged from >98.8 (TNT and triethylamine) to >99.97% (kerosene)
- Kerosene- the oxidation rate profile showed a rapid destruction of kerosene following the addition of the oxidant at 90°C - 99.97% within the first 70 minutes, followed by a slower destruction rate during the reminder of the test, with a destruction rate of 99.99% after 140 minutes
- Chlorinated solvents - results showed that chlorinated solvents are readily oxidized by the process, without pretreatment. Data reported on the extent of oxidation after 1 hr ranged from 0.967 to 0.996; however, the pretreatment step avoids the need to pressurize the oxidation step to avoid entrainment of the volatile solvents in the CO_2 offgas
- PCBs - results showed that very dilute solutions of PCBs can be treated to below detection limits by the process, both with and without pretreatment; little difference was observed with and without pretreatment; pretreatment was determined not to be necessary since PCBs are not volatile

Costs:

- Projected costs for a full-scale DCO process were calculated for a 50 kg/day plant operating at an 80% capacity factor; costs were estimated for two scenarios - recycling the expended oxident and not recycling
- If recycled, the projected cost is $9.88/kg of carbon in the waste, including the cost of electrical energy ($2.63), labor ($3), and capital cost ($1.92) plus profit and G&A (30%)
- If not recycled, the projected cost is $79/kg of carbon in the waste based on the equivalent weights of sodium peroxydisulfate (119 g/equivalent) and carbon (3 g/equivalent), a bulk cost for sodium peroxydisulfate ($0.73/lb), and an assumed 80% stoichiometric efficiency

Description:

In 1992, researchers at LLNL began developing the DCO process, a nonthermal, low temperature, aqueous based technology, for use in mixed waste treatment, chemical demilitarization and decontamination, and environmental remediation. A pilot-scale demonstration of the DCO process was conducted on a number of waste streams including concentrated wastes such as TNT, kerosene, triethlyamine, ion exchange resins, and ethylene glycol; chlorinated solvents such as TCE, PCE, methylene chloride, and chloroform; and low concentrations of PCBs in solution. The pilot-scale DCO process included a pretreatment (hydrolysis) step, used for highly chlorinated volatiles and a three-stage oxidation process performed in 15L reactors.

The results of the pilot-scale testing showed that the DCO process can treat a variety of organic waste streams. The destruction rate for the concentrated wastes was >98%, chlorinated solvents were readily oxidized using the three-stage oxidation only (without hydrolysis), and concentrations of PCBs were reduced to below detection levels both with and without pretreatment. According to LLNL, further research is not needed before scale-up of the technology, however, treatability studies are recommended for each candidate waste stream. Considerations in selecting DCO to treat a waste stream include the matrix and physical properties of the waste, waste composition and characteristics, and the target degree of oxidation/destruction removal efficiency.

Acid Digestion of Organic Waste at Savannah River Site, Aiken, South Carolina

Site Name:
Savannah River Site

Location:
Aiken, South Carolina

Period of Operation:
1996 to 1997

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstrate acid digestion of organic wastes as an alternative to incineration

Cleanup Type:
Bench and pilot scale

Contaminants:
Organic wastes and simulated radioactive wastes; no specific contaminants identified

Waste Source:
Nuclear processing operations

Contacts:

Principal Investigator:
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Technology:
Acid Digestion Process
- Process consists of an oxidation vessel, acid recycle and offgas treatment system, and acid stabilization and waste immobilization system
- Organic destruction takes place in oxidation vessel; waste is added to a bath of 14.8M phosphoric acid containing 0.5 to 1.0M nitric acid
- The vessel is heated to 150 to 200°C under pressure of 0 to 20 psig
- Bench-scale tests were conducted in units with 2-5 L capacity and pilot-scale tests in a 40 L glass reactor

Type/Quantity of Media Treated:
Organic wastes
- Cellulose (240 gms of KimWipes^{TM}), neoprene, polyethylene, and PVC

Regulatory Requirements/Cleanup Goals:
- Determine applicable organic wastes for technology, and related operating conditions
- No specific cleanup goals were identified

Results:
- Tests were conducted on cellulose, neoprene, polyethylene, and PVC
- Tests on cellulose showed that 240 gms of KimWipes^{TM} were oxidized to CO_2 and H_2O in 70 mL of acid and residual phosphoric acid was stabilized, providing for a volume reduction of 50 to 100 fold
- Tests showed that dissolution time for organic wastes depends on the type of waste, temperature, pressure, and acid concentration
- The dissolution rate for mixtures of waste types will be limited by the PVC dissolution rate, even when PVC is present in small quantities

Costs:
- Projected costs for full-scale acid digestion systems are under preparation, but were estimated to range from $2,000,000 to $8,000,000 for design, construction, and demonstration

Acid Digestion of Organic Waste at Savannah River Site, Aiken, South Carolina

Description:
Bench- and pilot-scale tests of an Acid Digestion system were conducted at DOE's Savannah River Site in 1996 and 1997. This technology was tested using job control wastes – organic waste forms consisting of materials such as cellulose, neoprene, polyethylene, and PVC. Acid Digestion is one of several Alternative Oxidation Technologies (AOT) under consideration by SRS for treatment of their plutonium 238 contaminated job control wastes.

Acid Digestion consists of dissolution of organic materials in a solution of nitric acid in phosphoric acid, and is conducted at operating conditions of 150 to 200ºC and 0 to 20 psig. Tests were conducted on cellulose, neoprene, polyethylene, and PVC, and showed that dissolution time for organic wastes depended on the type of waste, temperature, pressure, and acid concentration. Further, tests showed that the dissolution rate for mixtures of waste types will be limited by the PVC dissolution rate, even when PVC is present in small quantities. Because the process involves the use of nitric acid, controlling the reaction is an important safety consideration. Issues associated with monitoring the oxidation rate and water content need to be resolved for full-scale deployment of the technology.

Remotely Operated Scabbling at Argonne National Laboratory-East Argonne, Illinois

Site Name: Argonne National Laboratory-East	**Location:** Argonne, Illinois
Period of Operation: Not identified	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Demonstration of a remotely-operated scabbler to decontaminate radioactive concrete flooring	**Cleanup Type:** Field demonstration
Contaminants: Radionuclides • Beta/gamma radiation	**Waste Source:** Nuclear processing operations
Contacts: **Technical Contacts:** Linda Lukart-Ewansil Pentek, Inc 412-262-0725 pentekusa@aol.com Susan Madaris Florida International University 305-348-3727 madariss@eng.flu.edu **DOE Contact:** Richard Baker DOE, Chicago Operations Office 630-252-2647 richard.baker@ch.doe.gov	**Technology:** Remotely-Operated Scabbler • Pentek, Inc. Moose® scabbler • Consists of three subsystems - scabbling head assembly, on-board, high-efficiency particulate (HEPA) vacuum system, and six-wheeler chassis; remote operation performed using a small control panel attached to the scabbler by a tether (50-ft used for demonstration) • Scabbling head - seven 2 1/4-in diameter reciprocating scabbling bits, each with a 9-point tungsten carbide-tip capable of delivering 1,200 hammer impacts/min • HEPA vacuum system - two-stage positive filtration system that deposits waste into an on-board 23-gal drum • Chassis - independent skid steering for 360-degree rotation • During demonstration - average rate of scabbling - 130ft^2/hr for a 2-person crew **Type/Quantity of Media Treated:** Debris (concrete floor)

Regulatory Requirements/Cleanup Goals:
- The objectives of the demonstration were to evaluate the remotely-operated scabbler for concrete flooring contaminated with beta/gamma radiation

Results:
- During the demonstration, the scabbler removed an average of 1/8-inch concrete from 620ft^2 of the concrete floor
- Contamination levels (total beta/gamma radiation) reduced from a maximum of 105,000 dpm/100 cm^2 to 3,500 dpm/100 cm^2
- Waste generated - 37ft^3 mix of powder and small chips of paint and concrete

Costs:
- Costs for the Pentek Moose® - $165,000 equipment cost; $1,995/day labor rate (two trained operators); and $2,400 for replacement parts
- For the cost analysis, the Pentek Moose® was compared to a baseline technology of manual scabbling, using the demonstration area (620ft^2) and a hypothetical job size of 2,500 ft^2 (area requiring one week of effort)
- The Pentek Moose® was more expensive than the baseline technology for the smaller area; but was comparable to the baseline technology for the larger area
- The report includes a detailed analysis of the effect of labor rates, equipment transportation costs, waste disposal costs, and other factors on the cost of the technology

Remotely Operated Scabbling at Argonne National Laboratory-East
Argonne, Illinois

Description:
The Pentek Moose® is a remotely-operated scabbler used to scarify concrete floors and slabs. A demonstration of the technology was conducted at the Argonne National Laboratory-East, CP-5 Reactor on a floor area ($620ft^2$) contaminated with beta/gamma radiation. The Moose® includes a head assembly, on-board, high-efficiency particulate (HEPA) vacuum system, and six-wheeler chassis. The scabbler is operated remotely using a small control panel attached to the scabbler by a tether, 50 to 300 ft in length. A 50-ft tether was used for the demonstration.

A two-person crew, one person to operate the scabbler and one to manage hoses and cords, removed an average of 1/8 in concrete from an area of $620ft^2$ or at a rate of $130ft^2/hr$. Total beta/gamma radiation levels were reduced from a maximum of 105,000 dpm/100 cm^2 to 3,500 dpm/100 cm^2 following the demonstration. Approximately $37ft^3$ of waste was generated by the scabbling, consisting of a mixture of powder and small pieces of paint chips and concrete. The cost analysis showed that a number of factors affect the cost of the remotely-operated scabbler compared to the baseline of manual scabbling, including labor rates, costs to transport equipment, and waste disposal. The system is commercially available; however, several design improvements were suggested based on the results of the demonstration including eliminating the need for a second operator, increasing the size of the waste drum from 23-gal to 55-gal, and adding a second vacuum connection to the rear of the unit to collect small pieces of debris.

Soft Media Blasting at the Fernald Site, Fernald, Ohio

Site Name:
Fernald Site

Location:
Fernald, OH

Period of Operation:
August 19 - September 5, 1996

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstration of soft blast media to clean surfaces contaminated with uranium

Cleanup Type:
Field demonstration

Contaminants:
Radionuclides
- Enriched uranium (1.34 wt-% U-235)
- Contaminant levels of 18,000 dpm/100 cm^2 measured prior to demonstration

Waste Source:
Residue from enriched uranium processing operations

Contacts:

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Technology:
Soft Media Blasting
- Compressed air is used to propel soft blast media through a hose onto the contaminated surface; soft media traps and absorbs contaminants on impact
- Air compressor - minimum requirements (250 ft^3/min of air; 120 psi line pressure at the feed unit); for demonstration- 375 ft^3/min, 150 psi
- Feed unit - contains media mixture; connected to a hose (1 1/4-in. diameter; 25-ft long) fitted with a venturi-style tungsten carbide blast nozzle (3/8 in and 1/2 in nozzles tested during demonstration)
- Blast pressure - 45 psi; media flow - 20-25 lbs
- Six grades of media available (color-coded by grade); two grades of media were tested - green media containing no abrasive; brown media containing Starblast® abrasive
- Demonstration involved cleaning a settling tank contaminated with enriched uranium process residue

Type/Quantity of Media Treated:
Debris (concrete)

Regulatory Requirements/Cleanup Goals:
- Performance objectives included cleaning effectiveness (based on amount of residual radioactivity) and production rate
- Evaluate the technology for use in cleaning radioactive-contaminated surfaces

Results:
- Radiation levels were below the minimum detectable count rate (MDCR) following the demonstration
- Production rate was 92 ft^2/hr; rate was slower than expected - worker time was limited to 1 hr/day because of the noise generated by the system (106 to 113 dB)
- Brown media was effective on thick dirt; brown media generated more dust than the green media

Costs:
- Demonstration cost for soft media blasting - \$4.60/ft^2
- Projected full-scale costs are comparable to baseline technology (high-pressure water washing) for an area of 900ft^2 or larger

Soft Media Blasting at the Fernald Site, Fernald, Ohio

Description:
A field demonstration of Soft Media Blasting Technology (SMBT) was performed at the Fernald Site to evaluate the capability of the technology for cleaning radioactively-contaminated surfaces. SMBT uses compressed air to propel soft blast media onto the contaminated surface, with the soft media trapping and absorbing contaminants on impact. Six grades of media are available for the SMBT, manufactured by AEA Technologies, Inc. For the demonstration, two grades were tested - one containing no abrasive and one containing the Starblast® abrasive. A settling tank contaminated with enriched uranium process residue was used for the demonstration.

The results of the demonstration showed that the SMBT reduced radiation levels from 18,000 dpm/100 cm^2 to MDCR. The production rate of 92 ft^2/hr was slower than the baseline technology of high-pressure washing. Because the system was noisy, the time an individual could work was limited. The demonstration cost for soft media blasting was \$4.60/ft^2, more expensive than the baseline technology. However, the projected full-scale costs for SMBT are comparable to the baseline technology for an area of 900ft^2 or larger. Issues associated with full-scale implementation include the noise level produced by the system and improving the ergonomic design of the nozzle/hose assembly to make it less awkward to use. While the media was not recycled during the demonstration, a unit (Classifier Unit) can be added to the system for this purpose. The decision to not recycle the media during the demonstration was based on a concern that the feed and classifier units would not be successfully decontaminated following repeated recycling of the contaminated media.

Concrete Grinder at the Hanford Site, Richland, Washington

Site Name:
Hanford Site

Location:
Richland, WA

Period of Operation:
November 1997

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstration of a light weight hand-held grinder to decontaminate radioactive concrete surfaces

Cleanup Type:
Field demonstration

Contaminants:
Radionuclides
- Beta/gamma radiation

Waste Source:
Operation of a nuclear research reactor

Contacts:

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Greg Gervais, USACE, 206-764-6837

DOE Contacts:
John Duda, FETC, 304-285-4217
Jeff Bruggeman, DOE-RL, 509-376-7121

Technology:
Concrete Grinding
- Flex Model LD 1509 FR hand-held concrete grinder (6 lbs)
- 5-in diamond grinding wheel (10,000 rpm)
- 1.25-in. vacuum port for dust extraction
- Powered by 110 VAC, 11 amps

Type/Quantity of Media Treated:
Debris (concrete) - 54ft^2

Regulatory Requirements/Cleanup Goals:
The objectives of the demonstration were to evaluate the capability of a light weight, hand-held grinder in removing concrete

Results:
- Removed concrete from 54ft^2 of walls and floors in the demonstration area to a depth of 1/16 in. at a rate of 48ft^2/hr
- Contamination levels following demonstration were below free-release levels

Costs:
- The costs for the Flex LD 1509 FR concrete grinder are - $649 equipment cost plus $205 for a replacement diamond grinding wheel; grinder can be rented for $25/day or $75/week
- The cost for the hand-held grinder were 40% less than the baseline technologies (scaller and scabbler)

Description:
The Flex concrete grinder is a lightweight, hand-held unit used to remove concrete and coatings from concrete surfaces. The electric powered grinder is equipped with a diamond grinding wheel and a vacuum port for dust extraction. The grinder was demonstrated on walls and flooring at the C reactor that were contaminated with beta/gamma radiation.

During the demonstration, the grinder removed concrete to a depth of 1/16 in from a total area of 54ft^2. At the end of the demonstration, radioactivity levels were below free-release levels. The Flex grinder was compared to two baseline technologies - scabbler and scaler. The Flex grinder was found to be easier to use, more flexible, and more efficient that the baseline technologies, and overall to cost about 40% less. However, the life of the grinding wheel (manufacturer recommended change after 500ft^2 at a depth of 1/16 in and the cost of a replacement wheel ($205) should be factored into the decision to use the technology. No specific changes or modifications to the grinder are needed for full-scale deployment.

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Concrete Shaver at the Hanford Site, Richland, Washington

Site Name: Hanford Site	**Location:** Richland, WA
Period of Operation: November 1997	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Demonstration of a concrete shaver to decontaminate radioactive concrete surfaces	**Cleanup Type:** Field demonstration
Contaminants: Radionuclides • Beta/gamma radiation	**Waste Source:** Operation of a nuclear research reactor

Contacts: **Vendor Contact:** Ian Bannister Marcrist Industries Limited +44 (0) 1302 890888 **Technical Contacts:** Stephen Pulsford, BHI, 509-373-1769 Greg Gervais, USACE, 206-764-6837 **DOE Contacts:** John Duda, FETC, 304-285-4217 Glenn Richardson, DOE-RL, 509-376-7121	**Technology:** Concrete Shaver • Marcrist Industries Limited Model DTF25 concrete shaver • Electric-powered, self-propelled, walk behind concrete and coating removal system • 10-in. wide diamond impregnated shaving drum with 5-in. blades; vacuum port for dust extraction • Weighs 330 lbs; requires 380-480 volt, 3-phase power; minimum 16 amps • Variable cutting depth up to 0.5 in.; can reach to within 3 in. of wall/floor interface or obstruction • Demonstrated on radioactive-contaminated concrete floor **Type/Quantity of Media Treated:** Debris (concrete)

Regulatory Requirements/Cleanup Goals:
The objectives of the demonstration were to evaluate the capability of the shaver in removing contaminated concrete surfaces

Results
- Removed concrete from 816 ft^2 of floor space in the demonstration area to a depth of 1/8 in. at a rate of 128 ft^2/hr
- Contamination levels following demonstration were below free-release levels**:**

Costs:
- The costs for the Marcrist Industries Limited Model DTF25 concrete shaver are - $10,700 equipment cost plus $7,161 for a set of replacement blades (100 blades)
- Unit cost of \$1.32/ft^2, assuming a rate of 128 ft^2/hr
- The cost for the shaver is 50% less than the baseline technology (scabbler)

Description:
The Marcrist Industries Limited Model DTF25 concrete shaver is an electric-powered, self-propelled, walk behind system used to remove concrete and coatings from concrete surfaces. The electric powered shaver is equipped with a diamond impregnated shaving drum and a vacuum port for dust extraction. The shaver was demonstrated on concrete flooring in two rooms at the C reactor that were contaminated with beta/gamma radiation.

During the demonstration, the shaver removed concrete to a depth of 1/8 in from a total area of 816ft^2. At the end of the demonstration, radioactivity levels were reported to be below free-release levels. The shaver was compared to the baseline technology - scabbler - and was found to be as much as five times faster, produce less worker fatigue, and save 50% compared to the baseline technology. The shaver requires the use of a HEPA filtration system and is designed to work on floors, but not walls. No specific changes or modifications to the shaver are needed for full-scale deployment.

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Concrete Spaller Demonstration at the Hanford Site, Richland, Washington

Site Name:
Hanford Site

Location:
Richland, WA

Period of Operation:
January 16 - 27, 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
First demonstration of the hand-held concrete spaller on contaminated surfaces

Cleanup Type:
Field demonstration

Contaminants:
Radionuclides
- Beta and gamma radioactivty

Waste Source:
Nuclear processing operations

Contacts:

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DOE Contacts:
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Technology:
Concrete Spaller
- Hand-held unit weighing about 30 lbs
- Components include spalling bit, removable metal shroud, hydraulic cylinder rated at 9 tons, and hydraulic pump rated at 10,000 psi
- Pre-drill holes in surface (2.5-cm diameter) in a honeycomb pattern
- Spaller bit inserted into hole, the hydraulic valve opened causing bit to expand and breaking off a chunk of concrete; concrete chunks were collected in the metal shroud
- A water spray was used to control dust emissions during the demonstration

Type/Quantity of Media Treated:
- Debris - 4.6m^2
- Contaminated concrete walls and floors

Regulatory Requirements/Cleanup Goals:
- The objectives of the demonstration were to evaluate the capabilities and design features of the concrete spaller for removing contaminated concrete surfaces
- No specific cleanup goals were identified

Results:
- During the demonstration, the concrete spaller removed concrete from an area of 4.6 m^2 to a depth of 3 mm to 50 mm; the removal rate was 1.3m^2/hr
- Pre-drilling was relatively slow; however, faster drills are available for this step
- Little dust was generated by the spaller

Costs:
- Operating costs for the demonstration were about 22% higher than the baseline technology (scabbler and scaler) because of the problems encountered with the drill (slower than expected and inexperienced crew)
- For the cost analysis, operating costs were estimated for an improved concrete spaller technology (adequate drill and experienced crew) - \$128/m^2, assuming a depth of 3-mm
- Operating costs for the improved spaller are 15% less the costs for the baseline tools (scaler at \$155/m^2 and scabbler at \$156/m^2)

Concrete Spaller Demonstration at the Hanford Site, Richland, Washington

Description:
The concrete spaller, developed by the Pacific Northwest National Laboratory, is a hand-held tool used for decontaminating concrete surfaces. The spaller includes a 9-ton hydraulic cylinder and a patented spalling bit that is run by a 10,000 psi hydraulic pump. Holes are drilled into the concrete in a honeycomb pattern and the spaller bit inserted into each hole. The hydraulic valve is opened, expanding the bit, and the concrete is removed in chunks up to 2 inches thick and collected in a metal shroud attached to the spaller. The unit can be used on flat or slightly curved concrete walls and floors, and can be equipped with a vacuum filtration unit for particulate control.

The concrete spaller was demonstrated at DOE's Hanford site in Richland, WA on two wall areas in the fan room of the C Reactor facility. The walls were contaminated with beta/gamma radioactivity. During the demonstration, the spaller removed 4.6 m^2 of contaminated surface to a depth of 3 mm to 50 mm, which was deeper than the baseline technologies (scaler and scabbler). The operating cost of the spaller under optimal conditions is $\$128/m^2$, which is less than the costs for the baseline tools (scaler at $\$155/m^2$ and scabbler at $\$156/m^2$). Considerations for future development and use of the technology include the need for a simplified design or manufacturing technique for the spalling bit (which was found to be fairly difficult to manufacture), the addition of a water spray nozzle to the drill to eliminate the need for a second worker to manually apply water during drilling, and the additional of an automatic hydraulic control valve.

Stabilization Using Phosphate Bonded Ceramics at Argonne National Laboratory, Argonne, Illinois

Site Name:
Argonne National Laboratory

Location:
Argonne, IL

Period of Operation:
Not identified

Cleanup Authority:
RCRA and NRC

Purpose/Significance of Application:
Demonstration of phosphate-bonded ceramics to stabilize a variety of high salt-containing wastes

Cleanup Type:
Development tests

Contaminants:
Metals

- Oxide forms of cadmium, chromium, lead, mercury, and nickel were added to the waste stream at concentrations of 1,000 mg/kg each

Waste Source:
Surrogate waste streams containing high levels of nitrate salts and chloride and sulfates similar to those found at DOE facilities

Contacts:

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Technology:
Stabilization using phosphate bonded ceramics

- 50/50 blend of magnesium oxide and monopotassium phosphate powder mixed with water, additives, and waste
- Mixed for 20-30 minutes; waste form set for 2 hours, then cured for 14 days
- Initial testing performed to determine effects of different test scenarios on waste forms conducted on surrogate salt solutions and on surrogate salt waste streams containing activated carbon and ion exchange resins
  - Salt solutions - saturated solutions of $NaNO_3$ (50-wt%) and NaCl (10-wt%); RCRA metals (Cd, Cr, Pb, and Hg) added at 5,000 mg/kg each; additives included 50-wt% Class-F fly ash and 1-wt% K_2S to tie up Hg
  - Salt waste streams with activated carbon and ion exchange resins - mix included nitrate, sulfate, and chloride salts (30%), Na_2CO_3, and CsCl (to simulate a radioactive component)
- Based on results, additional tests were performed on two salt surrogates - one containing a high quantity of nitrate salts (58-wt%); the other high quantities of chloride and sulfates (70-wt%); RCRA metals (Cd, Cr, Pb, Hg, and Ni) added at 1,000 mg/kg each;
- Waste forms tested for density, compressive strength, and flammability (nitrate wastes)

Type/Quantity of Media Treated:
Salt-containing waste streams

Regulatory Requirements/Cleanup Goals:
RCRA Land Disposal Restriction (LDR) standards and NRC guidelines

- Universal Treatment Standards (UTS) for metals
- NRC leach index of 6; compressive strength of 500 psi

Stabilization Using Phosphate Bonded Ceramics at Argonne National Laboratory, Argonne, Illinois

Results:
Waste forms from salt solutions of $NaNO_3$ (50-wt%) and NaCL (10-wt%):
- Densities of 1.8 g/cm^3 and 1.72 g/cm^3, respectively and compressive strengths of 1,800 psi and 3,500 psi, respectively
- Passed the UTS standards for metals, with the exception of Cd; attributed to the less acidic conditions of the test (pH 4) that slowed reaction of Cd with the phosphate; Cd was fully stabilized in subsequent tests at lower pH levels
- Marginally passed leach index criteria with leach levels of 6.86 and 6.7, respectively, indicating slow salt leaching; additional binding or coating techniques may be needed to prevent salt leaching from deteriorating the waste

Waste forms from salt solutions containing activated carbon and ion exchange resins:
- For the 60-wt% and 70-wt% loadings - had densities of 1.24 g/ml and 1.32 g/ml and compressive strengths of 2,224 psi and 5,809 psi, respectively
- Passed the UTS standards for metals

MWFA salt surrogates:
- Had densities in the range of 1.7-2.0 g/cm^3 and compressive strength in the range of 1,400-1,900 psi
- Passed the UTS standards for metals
- Leach index results showed that process was only marginally successful in retaining NO_3 and CL anions; modifications to the basic formulation for the process were made including adding fly ash to the binder and a polymer coating to the waste form, which increased the leach index to as high as 12.6

Costs:
- Projected cost for full-scale stabilization using phosphate bonded ceramics are capital costs of about $2 million, including equipment design and development, and operating costs of about $6,510 per cubic meter of waste form, including labor and materials; disposal costs are estimated to be $2,836 per cubic meter of waste
- Compared to the baseline technology (basic Portland cement), the operating costs are higher ($6,510 versus $4,300 per cubic meter of waste form), but the disposal costs are lower ($2,836 versus $3,700 per cubic meter of waste)

Description:
A series of development tests were conducted at the Argonne National Laboratory to validate the stabilization of salt-containing wastes using a patented chemically bonded phosphate ceramics (CBPC) process. The low-temperature process uses magnesium oxide and monopotassium phosphate to form a low porosity, dense waste form consisting mainly of a ceramic magnesium potassium phosphate barrier. Various tests were performed using a number of mixed waste surrogates, including saturated salt solutions, salt surrogate containing activated carbon and ion exchange resin, and two MWFA recommended dry salt waste surrogates that represented actual wastes found at DOE facilities.

The results of the tests showed that the waste forms produced by the CBPC process met the RCRA UTS standards for metals and the NRC disposal criteria. Flammability test results showed the waste forms containing oxidizing salts (nitrates) to be stable and safe. Based on the results of the testing, additional testing of the salt waste form is recommended before full-scale deployment, such as the effects of salt anion leaching over time. For different waste streams, additional analytical and development work would be needed to qualify wastes for disposal and to verify the operating parameters for the specific wastes.

Stabilize Ash Using Clemson's Sintering Process at Clemson University, Clemson, South Carolina

Site Name: Clemson University	**Location:** Clemson, SC
Period of Operation: 1995	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Treatability study of stabilization of mixed waste fly ash using a sintering process	**Cleanup Type:** Bench scale
Contaminants: Metals • Fly ash contained heavy metals - cadmium (5,000 mg/kg), chromium (1,000 mg/kg), and lead (35,000 mg/kg)	**Waste Source:** Fly ash from the WERF incinerator at INEEL

Contacts:

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Technology:
Stabilization using Clemson's Sintering Process

- Used a high iron/high potassium aluminosilicate clay material - Red Roan Formation (RRF)
- A preliminary study and three statistically designed experiments performed to evaluate and optimize processing parameters
- Preliminary study - 67 vol% to 50 wt% equivalent fly ash/RRF mixture and a high moisture content (18.1 wt%), pressed at 5,000 psi, then fired at 1,000°C to produce waste form pellets
- Experiment I - to evaluate the effects of different physical properties on the waste form included 16 batches to test varying formulations; batch size - 270 grams; material pressed at 1,000 psi then fired between 1,025 and 1,075°C
- Experiment II - to optimize factors from experiment I included 15 batches (500 grams each); fired between 1,025 and 1,075°C; TCLP leach testing performed on waste forms
- Experiment III - to further evaluate effects of four physical properties (moisture content, waste loading, mixing time, auger speed) involved 27 batches, prepared using varying formulation based on the results of the second experiment

Type/Quantity of Media Treated:
Incinerator fly ash

Regulatory Requirements/Cleanup Goals:
RCRA Land Disposal Restriction criteria

- TCLP concentrations in mg/L - cadmium (0.19), chromium (0.86), lead (0.37), and zinc (5.3)

Stabilize Ash Using Clemson's Sintering Process at Clemson University, Clemson, South Carolina

Results:

- Preliminary study - TCLP results were above the limits for cadmium, lead, and zinc
- Experiment I - significant factors affecting the waste form included firing temperature, the RRF particle size distribution, and waste loading
- Experiment II - TCLP results showed that leach values for metals increased with increased waste loadings and decreased as the temperature increased; TCLP limits were met when waste loadings were below 20% vol
- Experiment III - TCLP results showed that leach values for metals increased as the waste loading increased, decreased as moisture content decreased; mixing time and auger speed were not significant factors

Costs:

No methodology has been selected to date to evaluate costs associated with full-scale deployment of the Clemson stabilization process

Description:

A bench-scale treatability study was conducted at Clemson University in 1995 to determine whether stabilization using a sintering process could be used to immobilize DOE waste. The study was funded by DOE through a cooperative agreement with University Programs at the Savannah River Site. The process involves mixing a high iron/high potassium aluminosilicate clay material with the waste, pressing the material, then firing the material to produce a ceramic waste form. For this study, Red Roan Formation (RRF) was used as the clay material and fly ash from the WERF incinerator at INEEL (containing high levels of metals) was used as the waste. A preliminary study and three statistically designed experiments were performed to evaluate the process and to obtain operating data for use in future pilot-scale testing.

The results of the treatability study showed that the process can produce stable, low porosity waste forms that meet the RCRA TCLP limits for metals at waste loadings of 20% vol or lower. This waste loading was lower than originally anticipated. Other significant factors affecting the waste form included firing temperature and the particle size distribution of the RRF. The process is applicable to most inorganic homogeneous solids and sludges such as ash, soils, and particulates, but is not well siuted for aqueous and organic liquids or heterogeneous debris. Based on the results of the treatability study, a pilot-scale demonstration of the process is planned for FY 1999.

Mixed Waste Encapsulation in Polyester Resins at the Hanford Site

Site Name:
Hanford Site

Location:
Richland, WA

Period of Operation:
Not identified

Cleanup Authority:
RCRA and NRC

Purpose/Significance of Application:
Treatability study of various polyester resins to stabilize high salt-containing mixed waste

Cleanup Type:
Treatability study

Contaminants:
Metals and radionuclides
- Spiked metals concentrations in treatability study wastes - arsenic (159.3 mg/kg), barium (154.1 mg/kg), cadmium (119 mg/kg), chromium (151.3 mg/kg), lead (132.7 mg/kg), and selenium (140.9 mg/kg)
- Spiked radionuclide concentrations in treatability study wastes - cesium (1.2x10^5 pCi/L), cobalt (1.1x10^5 pCi/L), strontium (1.1x10^5 pCi/L), and tecnetium (1.3x10^5 pCi/L)

Waste Source:
Salt-containing mixed wastes from DOE processes and surrogate wastes

Contacts:

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Technology:
Microencapsulation by Polyester Resin
- Four polyester resins tested - polymer (trade name) - orthophthalic (S2293), isophthalic (Aropol™ 7334), vinyl ester (Hetron® 922-L25), and water extendable (Aropol™ WEP 662 - proprietary)
- WEP resin was tested on aqueous wastes; other three were tested on dry waste
- Initiator (catalyst) - cobalt naphthenate
- Mixer equipped with a variable speed paddle and sample molds for curing
- Dry waste added as free-flowing powder; aqueous waste was slurried
- Mixing time - 5 to 10 minutes at a low rate to homogenize waste; additional 2 to 5 minutes at a high rate after initiator added (until the temperature rises indicating the onset of curing)
- Curing molds placed in adiabatic chambers
- Three tests using surrogate wastes; one test using a Hanford waste stream

Type/Quantity of Media Treated:
Process waste streams

Regulatory Requirements/Cleanup Goals:
RCRA Land Disposal Restriction (LDR) and NRC disposal criteria
- Treatability test targeted to TCLP levels for RCRA heavy metals - cadmium (1.0 mg/L), hexavalent chromium (5.0 mg/L), lead (5.0 mg/L) and mercury (0.2 mg/L)
- NRC leachability indices - target of 6 or higher

Mixed Waste Encapsulation in Polyester Resins at the Hanford Site

Results:

Orthophthalic, isophthalic, and vinyl ester resins:
- For RCRA metals, TCLP results for resins were below the target levels for all metals except cadmium. Failure was attributed to the sampling method which required the mold be cut to a smaller size (9mm), possibly destroying the polyester coating. To counter the effect, fully coated polyester waste form molds of 9mm were specifically prepared for TCLP testing; this sample passed for all metals including cadmium
- Results were also compared to the UTS criteria - most samples failed for RCRA metals
- Polyester microencapsulation was validated for salt loadings of 30-wt% for all three resins, and for salt loadings of up to 70% for the orthophthalic resin

WEP resin:
- For RCRA metals, TCLP results were below the targeted levels for all metals
- Results were also compared to the UTS criteria - samples passed for all metals expect for cadmium
- For radionucides, the leachability indices ranged from 10.1 to 10.8

Costs:
- Projected full-scale cost for the polyester resin encapsulation process - capital cost of $2 million including equipment design and development and operating cost of $5,940/cubic meter of waste form
- Disposal cost of $2,100/cubic meter of waste form

Description:

The Mixed Waste Focus Area, a DOE Environmental Management (EM) -50 program, sponsored the development of five low-temperature stabilization methods as an alternative to cement grouting to stabilize salt-containing mixed waste. One of the alternative methods is microencapsulation using polyester resins. COGEMA Engineering Corporation performed a series of treatabilitiy studies and developmental tests of the technology at the Hanford site. The studies included encapsulation of salt-containing mixed wastes from the Handford site and with surrogate wastes spiked with contaminants. Four types of resins were tested: orthophthalic polyester, isophthalic polyester, and vinyl ester for dry waste, and a water-extendible polyester resin for aqueous wastes. The cured waste forms were evaluated against the RCRA LDR and NRC disposal criteria.

The results of the studies showed that the encapsulation of salt-containing mixed waste using polyester resins is applicable to inorganic, relatively homogeneous low-level mixed wastes containing high levels of salt. Further development is needed to identify chemical additives to reduce the solubility and toxicity of the RCRA metals. Other factors to be considered in future development of the process include safety controls to address potential flammable and unstable conditions when using polyester encapsulation, and additional research into the long-term effectiveness of the technology.

Innovative Grouting and Retrieval at the Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho

Site Name:
Idaho National Engineering and Environmental Laboratory (INEEL)

Location:
Idaho Falls, ID

Period of Operation:
Summer of 1994 (innovative grouting and retrieval)
Summer of 1995 (polymer grouting)
Summer of 1996 (variety of grouting materials)

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Field demonstration of innovative jet grouting and retrieval techniques that are applicable to TRU wastes

Cleanup Type:
Full scale and field demonstrations

Contaminants:
- Radioactive and nonradioactive wastes
- Demonstration used nonradioactive tracer to simulate radioactive materials

Waste Source:
Buried drums and waste from DOE operations

Contacts:

Technical Contact:
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Technology:
Innovative Grouting and Retrieval (IGR)
- Demonstrated on a waste pit (10 ft^3), loaded with 55-gal cardboard and steel drums, and cardboard boxes (4 ft^3) filled with waste and rare-earth tracer designed to simulate transuranic (TRU) pits
- Three phases - jet grouting, application of demolition grout, and retrieval of the waste
- Jet grouting - CASA GRANDE drill system and a high pressure displacement pump used to inject grout at a nominal 6,000 psi; total of 24 yds^3 of Portland cement injected into 36 grout holes, creating a monolith
- Demolition grouting - immediately following jet grouting, thin-walled, spiral-wrapped tubes were inserted into the holes and allowed to cure, after which the demolition grout (BRISTAR) was added to the tubes; however, the grout did not expand as planned and the soil/waste matrix was not fractured
- Retrieval - a backhoe bucket was used to remove the monolith

Wall Stabilization Technique Using Jet Grouting for Hot Spot Removal
- Created a U-shaped wall by jet grouting Portland cement into an existing cold test pit at INEEL containing drums and boxes
- Jet grouting phase - 52 holes jet grouted to create the wall (30 ft along back and sides of U extended 8 feet); used jet grouting apparatus at 6,000 psi; total of 24 yds^3 of Portland cement injected
- Stabilization evaluation phase - wall excavated and visually examined; no collapse or structural damage to wall during excavation and no visible voids; grout mixed with soil and formed a soilcrete material that filled some voids; neat Portland cement filled other voids

Jet Grouted Polymer for Waste Stabilization or as an Interim Technique Before Retrieval
- Demonstrated on two waste pits designed to simulate TRU pits containing drums; used 55-gallon drums containing cloth, paper, metal, wood, and sludge; tracer placed in each drum to simulate plutonium oxide
- Tested two formulations of an acrylic polymer - one to produce a hard, durable material for long-term encapsulation; one to form a soft material for retrieval
- Hard polymer pit - 18 holes jet grouted into 4.5 x 9 x 6 ft pit; after curing, hard polymer was fractured and removed
- Soft polymer pit - 15 holes jet grouted into 4.5 x 9 x 6 ft pit; after curing, removed with a backhoe

In Situ Stabilization
- Demonstrated variety of grouting materials - TECT grout, WAXFIT, Hermite, water-based epoxy, and Type H cement; jet grouted to form monoliths of buried waste

Innovative Grouting and Retrieval at the Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho

Type/Quantity of Media Treated:
Soil and debris
- Steel drums; cardboard boxes containing metal pipe, wire, and plate steel; paper

Regulatory Requirements/Cleanup Goals:
- Purpose of the demonstrations was to evaluate different jet grouting techniques for use in stabilization and hot-spot retrieval of waste; nonradioactive wastes used for demonstrations
- No specific cleanup goals were identified

Results:
- IGR - produced stable monolith; monolith was removed in 5 hrs; general soilcrete mix easily removed; grouted waste that were more difficult to retrieve included grouted boxes containing metal pipe, wire, and plate steel and grouted computer paper, which disintegrated during removal
- Wall - produced a solid wall with no visible voids; wall was stable and excavated intact
- Soft polymer - soft polymer material was removed easily; however, tracer material was detected at two-orders of magnitude above background; determined that one of the containers was not penetrated during drilling; but was punctured during removal releasing tracer
- Hard polymer - produced cured, stabilized monolith with no voids; easily fractured with a backhoe and removed
- Various grout materials - TECT, WAXFIT, and Type H materials are easily jet grouted and produced stable monoliths; Hermite and water-based epoxy cannot be jet grouted
- In general, grouting techniques did not spread tracer, indicating that release of radioactive particulates would be minimized during operations

Costs:
- Costs projected for IGR, jet grouting using TECT, and jet grouting using WAXFIT; costs developed for 1-acre; for IGR costs also developed for 4-acre TRU contaminated site
- IGR - projected cost is $19 million (1-acre) and $64 million (4-acre), including grouting and waste management, excavation, secondary waste management, and D&D equipment
- TECT - projected cost is $15 million, assuming pit is left in place permanently; includes costs for grouting and waste management and secondary waste management, but no costs for caps
- WAXFIT - projected costs is $20 million, assuming waste pit is a soft polymer and is retrieved; includes costs for grouting and waste management and retrieval operations
- Jet grouting technologies were less expensive than the baseline retrieval, packaging, and storage ($200 million for 1-acre; $305 million for 4-acres)

Description:
Between 1994 and 1996, a number of different innovative jet grouting techniques were demonstrated at INEEL to determine their potential for use in stabilization and retrieval of buried transuranic (TRU) and other wastes at DOE facilities. Nonradioactive debris containing a rare-earth tracer were tested on waste pits designed to simulate those found at TRU sites. Technologies demonstrated included innovative grouting and retrieval, wall stabilization techniques using jet grouting for hot-spot removal, jet grouted polymer for waste stabilization, and various grouting materials for stabilization.

The results of the demonstrations indicated that a number of the jet grouting technologies produce stable waste forms that are generally easy to remove, thus making the technology suitable for stabilization and for hot-spot removal. In addition, the costs for jet grouting and retrieval is up to 90% less than the costs for the baseline technology of retrieval, packaging, and storage. Further testing is need of the BRISTAR demolition grout, which did not perform as expected, and long-term durability studies of the materials are recommended, including development of monitoring systems to ensure complete encapsulation of the waste.

Polysiloxane Stabilization at
Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho

Site Name:
Idaho National Engineering and Environmental Laboratory (INEEL)

Location:
Idaho Falls, ID

Period of Operation:
1997 - 1998

Cleanup Authority:
RCRA and NRC

Purpose/Significance of Application:
Demonstration of polysiloxane to encapsulate high-salt content wastes

Cleanup Type:
Field demonstration

Contaminants:
Heavy Metals
- hexavalent chromium - 1.045 ppm in one surrogate waste
- oxides of lead, mercury, cadmium, and chromium at 1,000 ppm each in two surrogate wastes

Waste Source:
Salt-containing wastes designed to simulate wastes from DOE operations

Contacts:

Vendor Contact:
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Technology:
Stabilization using polysiloxane
- Polysiloxane is a part inorganic part thermosetting polymer; for the demonstration, Orbit Technology's polysiloxane material was used
- The base chemicals (SiH and SiOH) are mixed with the waste and reacted in the presence of a platinum catalyst to form the desired thermosetting polymer and hydrogen gas
- A filler such as quartz can be added to strengthen the waste form
- The resultant vinyl-polydimethyl-siloxane product is gelled, and cured to form a solid waste form
- For the demonstration, the process was tested on three different salt surrogates - Pad-A salts from INEEL, one high chloride salt surrogate, and one high nitrate salt surrogate

Type/Quantity of Media Treated:
Process waste streams

Regulatory Requirements/Cleanup Goals:
RCRA Land Disposal Restriction (LDR) and DOT
- Target TCLP levels for RCRA heavy metals - cadmium (1.0 mg/L), hexavalent chromium (5.0 mg/L), lead (5.0 mg/L) and mercury (0.2 mg/L); also compared to RCRA universal treatment standards (UTS)
- DOT oxidizer test for nitrate salt wastes
- NRC recommended compressive strength of at least 60 psi

Polysiloxane Stabilization at
Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho

Results:

- INEEL Pad-A salt surrogate waste form - met the target TCLP levels; but did not meet the UTS standard for chromium; had a compressive strength of 637 psi
- Chloride salt surrogate waste form - met the target TCLP levels; did not meet the UTS standard for cadmium or chromium
- Nitrate salt surrogate waste form - met the target TCLP levels; did not meet the UTS for chromium or mercury; passed the DOT oxidizer test

Costs:

- Cost for full-scale polysiloxzane treatment are about $8/lb or $573 per cubic foot of salt waste
- The cost for polysiloxane encapsulation is competitive with the baseline technology of Portland cement stabilization

Description:

The Mixed Waste Focus Area, a DOE Environmental Management (EM)-50 program, sponsored the development of five low-temperature stabilization methods as an alternative to cement grouting to stabilize salt-containing mixed waste. One of the alternative methods is stabilization using polysiloxane. A demonstration of Orbit Technology's polysiloxane encapsulation process for high-salt content wastes was performed at INEEL on three salt surrogates, representing wastes found at DOE facilities.

The results showed that the polysiloxane process produced a durable waste form for all three high-salt content surrogates. The waste forms met the target TCLP levels for heavy metals, and the more stringent UTS standards for several of the metals tested. The process is currently limited to nonaqueous solid materials. Treatability testing is recommended for specific wastes prior to use of this technology. In addition, long-term durability testing of the polysiloxane waste forms is needed.

Amalgamation of Mercury-Contaminated Waste using NFS DeHg^{SM} Process, Applied Technology Laboratories, Erwin, TX

Site Name:
U.S. DOE INEEL, ETTP, and DSSI Facilities (tests conducted at Applied Technology Laboratories, Erwin, TN)

Location:
Idaho and Tennessee

Period of Operation:
1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstrate amalgamation of elemental mercury

Cleanup Type:
Field demonstration

Contaminants:
Heavy metals
- Mercury

Waste Source:
Nuclear processing operations

Contacts:

Technology Vendor:
Nuclear Fuel Services, Inc.
Erwin, Tennessee

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Technology:
Amalgamation using the NFS DeHg^{SM} Process
- Prior to amalgamation, waste is sorted, shredded, and slurried to create a homogeneous mixture
- The first step in the process is to stabilize elemental mercury using one or more amalgamation agents (agents not specified)
- A possible second step is a chemical stabilization process using a proprietary reagent to break mercury complexes and allow removal of mercury as a precipitant; this step is required if the waste fails the cleanup criteria after the first step
- Treated material is produced as a presscake; filtrate is either recycled to the reactor or discharged
- Processing was conducted at ambient conditions in a ventilated hood

Type/Quantity of Media Treated:
Liquid mercury
- 51 kg from East Tennessee Technology Park, formerly the K-25 Site; characterized as RCRA Waste Code U151
- 23 kg from INEEL; contained oil at 17% by volume; characterized as RCRA Waste Code D009
- 1 kg from Diversified Scientific Services (DSSI); this material had been recovered from a thermal desorption treatability study; also D009

Regulatory Requirements/Cleanup Goals:
- Envirocare of Utah Waste Acceptance Criteria
- For mercury - TCLP leachate concentration of 0.20 mg/L; also considered UTS of 0.025 mg/L

Results:
- Wastes from INEEL (DSSI wastes were combined with those from INEEL) were treated with two step process; for mercury - TCLP leachate in presscake from second step averaged 0.05 mg/L (range 0.02 to 0.12 mg/L); TCLP leachate in oil phase was 0.03 mg/L; total of 15 amalgams weighed 114 kg
- Wastes from ETTP were treated with two step process; for mercury - TCLP leachate in presscake from second step averaged 0.05 mg/L (range 0.01 to 0.17 mg/L); total of 20 amalgams weighed 238 kg

Costs:
- Projected costs for treating more than 1,500 kg were $300/kg, assuming waste is elemental mercury, and does not include disposal costs of the treated waste

Amalgamation of Mercury-Contaminated Waste using NFS DeHg^{SM} Process, Applied Technology Laboratories, Erwin, TX

Description:
Nuclear Fuel Services (NFS) conducted a demonstration of an amalgamation technology on wastes containing elemental mercury. The NFS process consists of a two step process, where mercury is first treated using amalgamation agents and then with proprietary chemical stabilization agents, and is conducted in a hood at ambient conditions.

Wastes from ETTP, INEEL, and DSSI were tested using this process. Results showed that the process reduced the concentration of mercury to 0.05 mg/L (on average) for each of 35 batches tested, and that the product met the Envirocare Waste Acceptance Criteria. Projected costs for use of the technology were $300/kg and costs for treating smaller amounts of wastes, such as at a specific site, were projected to be prohibitive. The report discusses the possibility of a national procurement contract to lower the cost of the technology on a unit mass basis.

Amalgamation of Mercury-Contaminated Waste using ADA Process, Colorado Minerals Research Institute

Site Name:
U.S. DOE Los Alamos National Laboratory and Fernald Facilities (tests conducted at Colorado Minerals Research Institute)

Location:
New Mexico and Ohio

Period of Operation:
1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstrate amalgamation of elemental mercury

Cleanup Type:
Field demonstration

Contaminants:
Heavy metals
- Mercury

Waste Source:
Nuclear processing operations at U.S. DOE Los Alamos National Laboratory and Fernald Facilities

Contacts:

Technology Vendor:
ADA Technologies
Englewood, CO

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Technology:
Amalgamation using the ADA Process
- Process consists of combining liquid mercury with a proprietary sulfur mixture in a pug mill to stabilize the elemental mercury
- The pug mill was a dual shaft mixer 0.9 m long with a 0.1 m^2 cross section, and held 0.06 m^3 of material; the mixing blades were 14 cm long and overlapped; mixing speed was 50 rpm
- Mixing was concluded when the reaction exotherm subsided and free elemental mercury analysis indicated that more than 99% of the mercury had reacted
- Air above the pug mill was swept to remove mercury vapors and filtered through a HEPA filter and a sulfur-impregnated carbon filter to capture mercury
- Processing was conducted at ambient conditions

Type/Quantity of Media Treated:
Liquid mercury
- 112 kg of mercury from LANL and 20 kg from Fernald
- No radioactivity was detected in either waste stream
- The waste from Fernald contained significant amounts of water

Regulatory Requirements/Cleanup Goals:
- Envirocare of Utah Waste Acceptance Criteria
- RCRA TCLP limit for mercury - 0.20 mg/L

Results:
- Wastes were processed in 5 batches (4 from LANL and 1 from Fernald) of 20 to 33 kg/batch
- The amount of free mercury was reduced from 99.87 to 99.98% per batch
- TCLP mercury was less than 0.1 mg/L in each batch, with a mercury waste loading of 57%
- Product from the amalgamation process was found to meet the Envirocare Waste Acceptance Criteria
- Mercury vapor concentrations above the pug mill were below the TLV of 50 ug/m^3

Costs:
- Projected costs for full-scale amalgamation using the ADA Process were $300/kg for more than 1,500 kg, assuming waste is elemental mercury, and does not include disposal costs of the treated waste

Amalgamation of Mercury-Contaminated Waste using ADA Process, Colorado Minerals Research Institute

Description:
ADA Technologies conducted a demonstration of a proprietary amalgamation technology on wastes containing elemental mercury from Los Alamos and Fernald. The ADA process consists of combining liquid mercury with a proprietary sulfur mixture in a pug mill, and is conducted at ambient conditions.

Results showed that the process reduced the free mercury by 99.87 to 99.98%, and that the product met the Envirocare Waste Acceptance Criteria and passed the RCRA TCLP criteria for mercury. Projected costs for use of the technology were $300/kg and costs for treating smaller amounts of wastes, such as at a specific site, were projected to be prohibitive. The report discusses the possibility of a national procurement contract to lower the cost of the technology on a unit mass basis.

GTS Duratek (GTSD) Process for Stabilizing Mercury (<260 ppm) Contaminated Mixed Waste from U.S. DOE's Los Alamos National Laboratory

Site Name:
U.S. DOE Los Alamos National Laboratory (tests conducted at GTSD Bear Creek Operations Facility)

Location:
New Mexico

Period of Operation:
September 1997 to September 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstrate stabilization of low level mercury in radioactive wastes

Cleanup Type:
Treatability studies

Contaminants:
Heavy metals, Volatile Organics, and Radionuclides

- Mercury concentration was 230 mg/kg; TCLP 0.0399 to 0.184 mg/L
- DCE concentration was 11,000 mg/kg, vinyl chloride 220 mg/kg, methylene chloride 12,000 mg/kg
- Radionuclides included plutonium and strontium

Waste Source:
Nuclear processing operations

Contacts:

Technology Vendor:
GTS Duratek
Kingston, Tennessee

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Technology:
Stabilization

- Stabilization reagents involved addition of water and then cement to form a grout mixture; the mixture was then blended with sodium metasilicate and cured for two days
- Bench- and pilot-scale tests were conducted, at high and low waste loadings
- Pilot-scale tests were conducted in drums using a vertical in-drum mixer

Type/Quantity of Media Treated:
Sludge and Laboratory Wastes

- Four 55-gallon drums containing 1,253 lbs of sludge
- Three containers of lab packs from analysis of the sludge

Regulatory Requirements/Cleanup Goals:

- Land Disposal Restrictions for heavy metals (such as mercury - 0.025 mg/L) and organics
- Envirocare Waste Acceptance Criteria (WAC) for disposal

Results:

- At low waste loadings, mercury concentrations were reduced to values ranging from 0.00127 to 0.0169 mg/L, below the LDR standard of 0.025 mg/L; at high waste loadings, mercury was reduced to values ranging from 0.0024 to 0.0314 mg/L – one sample contained mercury above the LDR standard
- Several organic compounds and radionuclides were higher than the LDR standards or Envirocare WAC after treatment, including 1,1,1-trichloroethane, 1,1-dichloroethane, methylene chloride, lindane, DDE, heptachlor epoxide, and methoxychlor, strontium, and americium
- The vendor indicated that these results re-emphasized the importance of accurate characterization data; the high levels of organics were not expected based on the original characterization data provided by LANL
- Bench-scale tests showed mercury met LDR level in all 3 low load and 2 of 3 high load samples

Costs:

- Projected costs for a full-scale stabilization system using this technology were not developed

GTS Duratek (GTSD) Process for Stabilizing Mercury (<260 ppm) Contaminated Mixed Waste from U.S. DOE's Los Alamos National Laboratory

Description:
Sludge was generated at the Phase Separation Pits of the TA 35 facility of the Los Alamos National Laboratory (LANL) by addition of a caustic solution to the condensate and particulates removed from laboratory fume hood exhausts by the phase separators. The sludge and laboratory wastes from analysis of the sludge, were a mixed waste due to the presence of radionuclides, heavy metals, and RCRA-listed organic compounds.

Bench- and pilot-scale tests of the GTS Duratek process were conducted to stabilize the contaminants in the sludge and laboratory wastes. The GTS Duratek process includes addition of water, cement, and sodium metasilicate. The stabilized product met the LDR standard for mercury in all but one high load test sample. However, several VOCs, pesticides, herbicides, and radionuclides did not meet the LDR standards or Envirocare WAC after treatment. This result was attributed to inaccurate characterization data of the waste streams, which did not show the relatively high levels of organics.

Stabilize High Salt Content Waste Using Sol Gel Process at Pacific Northwest National Laboratory, Richland, WA

Site Name:
Pacific Northwest National Laboratory

Location:
Richland, WA

Period of Operation:
Not identified

Cleanup Authority:
RCRA and NRC

Purpose/Significance of Application:
Laboratory testing of the sol gel process to stabilize high salt content waste

Cleanup Type:
Laboratory scale treatability test

Contaminants:
Metals and salts
- Two salt-containing, nonradioactive surrogates - one with nitrate salts; one with chloride and sulfate salts
- Both contained 1,000 mg/kg each of lead, chromium, cadmium, and nickel (in the form of metal oxides)

Waste Source:
Salt waste surrogates that simulated nonradioactive wastes from DOE facilities

Contacts:

Technical Contacts:
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Technology:
Stabilization using the Sol Gel Process
- The Sol Gel processing is a general synthesis technique that uses hydrolysis and condensation to produce solid matrices from liquids
- Ceramic portion formed after tetraethlyorthosilicate (TEOS) was prehydrolized with acidified water (0.15M HCL) in tertrahydrofuran (THF)
- The polymer polybutadiene was added and the solution was refluxed for 30 minutes
- Salt waste surrogate was mixed into the solution and stirred until the solution thickened
- Solution was then transferred to a plastic container, allowed to gel, then capped (the cap was punctured with small holes to allow gas to escape) and dried in an oven at 66°C for a minimum of 24 hours, then placed in a vacuum oven at 70°C for three hours
- The resulting material was a polyceram waste form
- Process modified after initial test results showed open porosity in sample waste forms; to minimize open porosity, dried samples were submerged in a polycream or resin solution and placed under vacuum to allow infiltration, then dried overnight

Type/Quantity of Media Treated:
Salt waste surrogates - two surrogates tested at waste salt loadings of 50 to 70%

Regulatory Requirements/Cleanup Goals:
- RCRA TCLP criteria for metals
- Leachability index (LI) of at least 6.0 for the salt components
- Compressive strength of salt waste forms of at least 60 psi
- Final waste form must incorporate at least 10-wt% of the salt component

Stabilize High Salt Content Waste Using Sol Gel Process at Pacific Northwest National Laboratory, Richland, WA

Results:
- Initial samples met requirements for compressive strength and LI; however, forms contained open porosity which exacerbated leaching, resulting in the samples not meeting the TCLP limits for metals
- After process was modified to minimize open porosity, samples were below the TCLP limits for all metals and very near or below the UTS limits for metals (results for cadmium and chromium were reported slightly above the UTS limits, but results were below the practical quantification limits of the instrument)
- The second waste form samples contained 50% of the chloride/sulfate salt surrogate; data on compressive strength and LI were not available; however, report indicated that these samples were expected to be stronger and have a higher LI than the first samples

Costs:
- To date, no detailed cost analyses have been performed on this process
- The report included an order of magnitude estimate for the Sol-Gel process in the range of $600,000 to $1 million for design, capital equipment, installation, and startup costs, as well as obtaining the required environmental and operating permits

Description:
At the Pacific Northwest National Laboratory, DOE conducted laboratory scale testing of the Sol Gel process to stabilize high salt content waste. Two salt-containing, nonradioactive surrogates - one with high levels of nitrate salts and one with high levels of chloride and sulfate salts - were used for the tests to simulate wastes at DOE facilities. The Sol Gel process involved combining a polymer (polybutadiene) and an oxide-based ceramic (formed using TEOS, acidified water, and THF) to produce a solid material referred to as a polyceram. The resulting polyceram waste forms were tested to determine leachability and compressive strength at salt waste loadings of at least 10-wt%.

While initial samples met the requirements for compressive strength and leachability index, they did not meet the TCLP criteria because the form contained open porosity. To minimize open porosity, the process was then modified to include infiltration of dried samples with a resin. Test results for the infiltrated samples were below the TCLP levels and near or below the UTS levels. While a detailed cost analysis had not been performed on the process, an order of magnitude estimate indicates that the process would cost in the range of $600,000 to $1 million.

ATG Process for Stabilizing Mercury (<260 ppm) Contaminated Mixed Waste from U.S. DOE's Portsmouth, Ohio Facility

Site Name:
U.S. DOE Portsmouth, Ohio (tests conducted at Mountain States Analytical Laboratory)

Location:
Portsmouth, Ohio

Period of Operation:
1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstrate stabilization of low level mercury in radioactive wastes

Cleanup Type:
Field demonstration

Contaminants:
Heavy metals and Radionuclides

- Mercury concentration was 1.06 mg/mL
- Technetium-99 present at 680 pCi/g
- Other heavy metals included barium, cadmium, and chromium

Waste Source:
Nuclear processing operations

Contacts:

Technology Vendor:
Allied Technology Group
Fremont, CA

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Technology:
Stabilization

- Stabilization reagents included proprietary dithiocarbamate (DTC), phosphate, polymeric reagents, and generic reagents such as magnesium oxide and activate carbon
- Bench-scale and field demonstration tests were conducted
- Bench-scale tests showed that DTC without other reagents provided the best results
- Field demonstration tests were conducted on three-33 kg batches of waste, using a 7 ft^3 mortar mixer

Type/Quantity of Media Treated:
Ion exchange resin

- 160 kg of resin (liquid waste) containing <5% solids

Regulatory Requirements/Cleanup Goals:

- Universal treatment standard (UTS) for mercury of 0.025 mg/L

Results:

- Mercury concentrations were reduced on average from 1.06 to 0.0092 mg/L, below the UTS of 0.025 mg/L; 99% of the mercury was stabilized
- Cadmium, the other heavy metal present at concentrations higher than the UTS, was reduced on average from 0.371 to 0.053 mg/L, below the UTS of 0.11 mg/L; 86% of the cadmium was stabilized
- The average density of the treated waste was 1.17 kg/L, which was a 17% weight increase and a 16% volume increase from the untreated waste
- No mercury vapors or radioactivity was detected during the demonstration

Costs:

- Projected costs for a 1,200 lb/hr stabilization system included capital costs of $30,000 and operating costs of $95/hr of operation
- These correspond to a life cycle cost of $1.73/kg, without decontamination and decommissioning

ATG Process for Stabilizing Mercury (<260 ppm) Contaminated Mixed Waste from U.S. DOE's Portsmouth, Ohio Facility

Description:
Allied Technology Group (ATG) conducted a demonstration of stabilization of mixed wastes containing less than 260 ppm of mercury. The ATG technology used dithiocarbamate (DTC) to stabilize 160 kg of ion exchange resin containing <5% solids. The resin was contaminated with heavy metals including mercury and cadmium.

The DTC formulation stabilized mercury and cadmium to concentrations lower than the UTS, with a relatively small increase in weight and volume. A life cycle cost of $1.73/kg of waste was projected for use of this technology at a full scale.

Graphite Electrode DC Arc Furnace at the Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho

Site Name:
Idaho National Engineering and Environmental Laboratory (INEEL)

Location:
Idaho Falls, ID

Period of Operation:
1997-1998

Cleanup Authority:
RCRA and NRC

Purpose/Significance of Application:
Determine potential applicability of DC arc plasma furnace to treat a variety of wastes from DOE facilities

Cleanup Type:
Bench-scale studies and engineering-scale furnace (ESF) tests

Contaminants:
Metals, Radionulcides
- Plutonium-238 and heavy metals including lead

Waste Source:
Waste streams and surrogates from various DOE facilities

Contacts:

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Technology:
Graphite Electrode DC Arc Furnace
- ESF system included the furnace, power control systems, feed systems, off-gas system, and control system
- ESF - 3.5 ft diameter by 4 ft high stainless steel vessel enclosing the furnace hearth; graphite crucible was lined with Monofrax K-3 refractory; four graphite rods threaded into the crucible; layers of porous graphite, firebrick, and refractory material surround crucible; nitrogen used to prevent oxygen from attacking the graphite crucible
- ESF included penetrations for glass overflow discharge, furnace offgas, and pyrometer access; overflow section heated to temperatures as high as 1,500°C to keep glass molten for pouring
- Outer walls of furnace equipped with air cooling jacket and two cooling coils - to prevent glass migration throughout refractories and insulation
- Bottom drain - inductively heated/freeze-valve bottom drain for removing metals and/or slag from the bottom of the furnace
- Bench-scale testing included 43 nonradioactive waste tests and 5 radioactive waste tests
- Two ESF tests conducted in FY 1997 - one using feed spiked with heavy metals and with plutonium surrogates; one using nonradioactive debris
- First test feed rate was about 5 kg/hr and about 320 kg of feed material was processed over an 86-hour period; operational problems caused furnace to be shut down during second test
- One ESF test conducted in FY 1998 on Pantex neutron generators - process 150 neutron generators over a 21-hour period at a rate of 27 lbs/hr

Type/Quantity of Media Treated:
- INEEL wastes including soils, high metal wastes, organics/oils/solvents, and debris
- Slag from Rocky Flats
- Plutonium-238 waste from SRS
- Neutron generators (tritium and lead) - about 150

Regulatory Requirements/Cleanup Goals:
RCRA Land Disposal Restriction criteria for metals and NRC disposal criteria

Graphite Electrode DC Arc Furnace at the Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho

Results:

- The first 1997 test performed as planned with minor problems such as failure of the overflow heater, which was corrected; produced a uniform, homogeneous vitrified product with a low leach rate for TCLP metals; the behavior of Plutonium-238 was identical to that of Plutonium-239, with the majority of the plutonium partitioning in the glass phase
- During the second 1997 test, the furnace failed as a result of current firing through a fracture in the sidewall; the system was shut down and repaired
- 1998 test results showed that the ESF was capable of processing neutron generators, with the resulting glass form passing the TCLP test for metals; however, approximately 75% of the available lead partitioned to the offgas system (attributed to the glass collection problem) and 85% of the available tritium was released through the process stack
- Operational problems with the 1998 test included the inability to operate the bottom drain of the melter and the need to operate in a continuous overflow mode, causing problems with glass collection
- In general, high water content in sludges (30wt%) increased electrode corrosion, caused problems with feeding via the solids auger and caused water to collect in the off-gas system

Costs:

- Projected cost for full-scale - $50 to $80 million capital cost; operating costs of $12 to $18 million through the startup period and $48 to $62 million for a five year operating period
- Projected treatment and disposal costs - $7,400 to $10,800 per cubic meter, based on 17,000 cubic meters of waste
- Total life cycle costs estimated to be $124 to $184 million

Description:

A series of bench-scale tests using radioactive and nonradioactive wastes were conducted at INEEL to determine the potential for using a DC Arc Furnace for waste treatment. Several types of wastes were tested including Rocky Flats Pondcrete (slag); INEEL soils, high metals wastes, organics/oils/solvents; and debris; and an SRS 238Pu contaminated debris waste. A DC Arc ESF system, including the furnace, power control systems, feed systems, off-gas system, and control system, was used for two sets of tests of radioactive and nonradioactive wastes in 1997, and to test the ability to process neutron generators in 1998.

The results of the first 1997 test showed that the DC Arc Furnace could produce a solid, homogenous glass form that met the TCLP criteria for metals. The system was then shutdown during the second test when the furnace failed. Following repairs, the system was shown to be capable of processing neutron generators, with the glass form meeting the TCLP limits for metals. However, several operational difficulties led to the partitioning of a majority of the primary contaminants (tritium and lead) to the off-gas. Since these demonstrations, several design improvements have been made to the prototype system, including a second generation melter and improvements in the feed system and off-gas treatment systems.

Plasma Hearth Process at the Science and Technology Applications Research (STAR) Center,Idaho Falls, Idaho

Site Name: STAR Center	**Location:** Idaho Falls, ID
Period of Operation: 1993 through 1997	**Cleanup Authority:** RCRA and NRC
Purpose/Significance of Application: Demonstration of a plasma hearth furnace to treat metals and radionuclides in a variety of waste types	**Cleanup Type:** Bench scale and pilot scale
Contaminants: Metals and radionuclides • Nonradioactive cerium used in tests to simulate plutonium • Metals include arsenic, barium, cadmium, chromium, lead, mercury	**Waste Source:** • Wastes from DOE facility operations and air pollution control systems
Contacts: **Principal Investigators:** Ray Geimer SAIC 545 Shoup Ave. Idaho Falls, ID 83402 Telephone: 208-528-2144 Fax: 208-528-2194 E-mail: Ray Geimer@cpqm.saic.com Carla Dwight Argonne National Laboratory - West P.O. Box 2528 Idaho Falls, ID Telephone: 208-533-7651 E-mail: carla.dwight@anl.gov **MWFA Product Line Manager:** Whitney St. Michael Mixed Waste Focus Area Lockheed Martin Idaho Technologies Company Idaho National Engineering and Environmental Laboratory 2525 N. Freemont Idaho Falls, ID 83415 Telephone: 208-526-3206 Fax: 208-526-1061 E-mail: whitney@inel.gov	**Technology:** Plasma Hearth Process (PHP) • PHP is a high temperature thermal process that heats waste to a molten form, which is then cooled into a glass/crystalline waste form; equipped with an air pollution control system to remove particulates and volatiles in the offgas • PHP melt temperature - 1,650-2,200°C; • Three systems tested - nonradioactive bench-scale system (NBS), radioactive bench-scale system (RBS), and nonradioactive pilot-scale system (NPS) • NBS- batch system with a refractory lined fixed hearth vessel equipped with a 150 KW Retech RP75T transferred arc plasma torch; feed rate of 15 lbs/hr • RBS - batch system with a plasma chamber equipped with a 150 KW Retech RP75T transferred arc plasma torch; feed rate of 30 lbs/hr; holds eight, 1-gallon waste containers and includes offgas treatment system • NPS - 6.5 ft by 6.5 ft cylindrical hearth equipped with a 1.2 megawatt Retech RP600T plasma torch; feed rate of 1,000 - 1,500 lbs/hr; holds three, 55-gallon waste drums and includes offgas treatment **Type/Quantity of Media Treated:** • NBS - Fly ash, soil, sludges, debris (concrete, asphalt, sheet rock, steel), sodium nitrate • RBS - inorganic and organic sludges, debris (wood, graphite, and fire brick) • NPS - debris
Regulatory Requirements/Cleanup Goals: • RCRA Land Disposal Restriction (LDR) standards • Federal and state air emissions standards	

Plasma Hearth Process at the Science and Technology Applications Research (STAR) Center,Idaho Falls, Idaho

Results:

- Slag samples passed the RCRA limits for metals
- Cerium oxide (plutonium oxide surrogate) was found to primarily partition to the vitreous slag; slightly higher retention rates were noted for sludges as compared to combustible debris
- All high vapor pressure metals (mercury, cadmium, lead), except barium, partitioned to the offgas system, where they were removed prior to release from the stack
- Stack emissions were generally below the air emission limits, including total particulates and metals, except for mercury
- The process was shown to treat a wide variety of waste types

Costs:

Projected costs for full-scale system include:

- Capitals - $50 to $86.2 million for facility construction and outfitting
- Startup operating cost - $12 to $18 million
- O&M for a 5-yr period - $48 to $62 million
- Assuming 17,000 cubic meters of waste are treated, the projected unit cost for PHP is $7,400 to $10,800 per cubic meter.

Description:

DOE sponsored a series of bench- and pilot-scale tests of the Plasma Hearth Process (PHP) at the STAR Center in Idaho Falls, Idaho, conducted between 1993 and 1997. PHP is a high temperature thermal process that heats waste to a molten form, which is then cooled into a glass/crystalline waste form. Three PHP systems were tested on a wide range of wastes to evaluate the process for treating different wastes and to determine operating conditions. The three systems were a nonradioactive bench-scale system (NBS), radioactive bench-scale system (RBS), and nonradioactive pilot-scale system (NPS). The types of wastes tested included fly ash, organic and inorganic sludges, and a variety of debris; for the RBS system, nonradioactive cerium was used as a surrogate for plutonium wastes.

The results showed that PHP was capable of treating a wide variety of radioactive and nonradioactive wastes, meeting the RCRA LDR standards for metals and , with the exception of mercury, operating within the air emission requirements for the systems. Differences were noted between the behavior of sludges and debris in the system, such as higher retention rates for cerium oxide for sludges as compared to debris. Additional data are needed to better quantify the treatment of debris using PHP. Other issues to be considered for full-scale deployment include additional data on the behavior of radionuclides compared to the cerium surrogate, and a more detailed evaluation of PHP for high organic waste feeds.