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Abstracts of Remediation Case Studies

Volume 5

Federal
Remediation
Technologies
Roundtable
<www.frtr.gov>

Prepared by the

Member Agencies of the
Federal Remediation Technologies Roundtable

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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 56 case studies of site remediation applications prepared primarily by federal agencies. The case studies, collected under the auspices of the Federal Remediation Technologies Roundtable (FRTR), 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 (EPA), 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, and cover a variety of *in situ* and *ex situ* treatment technologies and some containment remedies. The case study reports and abstracts are available on a CD-ROM, which contains a total of 274 remediation technology case studies (the 56 new case studies and 218 previously-published case studies). Appendix A to this report identifies the specific sites, technologies, contaminants, media, and year published for the 274 case studies.

Abstracts, Volume 5, covers a wide variety of technologies, including full-scale remediations and large-scale field demonstrations of soil and groundwater treatment technologies. Additional abstract volumes will be prepared as agencies prepare additional case studies.

2001 Series

CD-ROM:	FRTR Cost and Performance Case Studies and Related Information, 2nd Edition; EPA-542-C-01-003; May 2001

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
Volume 5:	EPA-542-R-01-008; May 2001

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 users 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 also are available on individual agency web sites, such as for the Department of Energy.

In addition, a limited number of copies of the CD-ROM and Abstracts - Volume 5 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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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-scale projects. Previously, the Roundtable published 13 volumes and a CD-ROM of case study reports. At this time, the Roundtable is publishing a CD-ROM containing 56 new case study reports (274 reports total), primarily focused on contaminated soil and groundwater cleanup. The CD-ROM also includes 218 previously published reports.

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, contaminants and media treated, technology, cost and performance, and points of contact for the technology application. The case studies contain varying levels of detail, reflecting the differences in the availability of data and information about the application.

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; methyl tert-butyl ether (MTBE); metals; and radioactive materials.

Table 1 provides summary information about the technology used, contaminants and media treated, and project duration for the 56 technology applications in this volume. This table also provides highlights about each application. Table 2 summarizes cost data, including information about 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.) The cost data presented in the table were taken directly from 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).

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.

Appendix A to this report provides a summary of key information about all 274 remediation case studies published to date by the Roundtable, including information about site name and location, technology, media, contaminants, and year the project began. The appendix also identifies the year that the case study was first published. All projects shown in Appendix A are full-scale unless otherwise noted.

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	MTBE	Metals	Radionuclides			
Other *In Situ* Soil Treatment									
Alameda Point, CA (Electrokinetics)					●		Soil (38.4 m^3)	December 1997 to June 1998	Field demonstration of electrokinetic treatment of chromium in soil
Portsmouth Gaseous Diffusion Plant, X-231A Site, Piketon, OH (Hydraulic Fracturing)	●						Soil and Groundwater	1996 to 1998	Field demonstration of hydraulic fracturing with four types of remediation technologies
Incineration									
Drake Chemical Superfund Site, Operable Unit 3, Lock Haven, PA (Rotary Kiln Incineration)	●						Soil (273,509 tons)	January 1997 to April 1999	Use of on-site incineration to treat soil contaminated with VOCs and SVOCS, including herbicides
Thermal Desorption									
Metaltec/Aerosystems Superfund Site, Franklin Borough, NJ (Thermal Desorption)	●						Soil (4,215 yd^3)	December 1994 to January 1995	Use of thermal desorption to treat soil contaminated with chlorinated volatile organic compounds
New Bedford Harbor Superfund Site, New Bedford, MA (Thermal Desorption)							Sediment	November 1996	Demonstration of thermal desorption/gas phase chemical reduction to treat PCB-contaminated sediments
Reich Farm, Pleasant Plains, NJ (Thermal Desorption)	●						Soil (14,836 yd^3)	November 1994 to March 1995	Thermal desorption treatment of soils contaminated with VOCs and SVOCs
Rocky Flats Environmental Technology Site, Mound Site, Golden, CO (Thermal Desorption)	●						Soil (724.5 yd^3)	July to August 1997	Thermal desorption of soil contaminated with halogenated volatile organic compounds
Sarney Farm, Amenia, NY (Thermal Desorption)	●	●					Soil (10,514 tons)	August to December 1997	Thermal desorption treatment of soils contaminated with VOCs
Other *Ex Situ* Soil Treatment									
Brookhaven National Laboratory, NY (Physical Separation/Segmented Gate System)						●	Soil (625 yd^3)	May to June 2000	Use of a gate system to reduce volume of radioactive-contaminated soil requiring off-site disposal

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	MTBE	Metals	Radionuclides			
Idaho National Environmental and Engineering Laboratory (INEEL), ID (Physical Separation/Segmented Gate System)						●	Soil (442 yd^3)	May to June 1999	Use of a gate system to reduce volume of radioactive-contaminated soil requiring off-site disposal
Massachusetts Military Reservation, Training Range and Impact Area, Cape Cod, MA (Solidification/Stabilization)					●		Soil (23,168 yd^3)	February to June 1998	Use of a proprietary stabilization technology to treat lead in both *in situ* and *ex situ* soils
New Bedford Harbor Superfund Site, New Bedford, MA (Solidification/Stabilization)							Sediment	November to December 1995	Bench-scale testing of solidification/stabilization to treat PCB-contaminated sediments
New Bedford Harbor Superfund Site, New Bedford, MA (Solvent Extraction)							Sediment	June 1996	Demonstration of solvent extraction/dechlorination to treat PCB-contaminated sediments
New Bedford Harbor Superfund Site, New Bedford, MA (Vitrification)							Sediment	July to August 1996	Demonstration of vitrification to treat PCB-contaminated sediments
Stauffer Chemical Company, Tampa, FL (Composting)			●				Soil (905 yd^3)	June 1997 to September 1998	Demonstration of composting technology for treatment of soil contaminated with chlorinated pesticides
Drinking Water Treatment									
Charnock Wellfield, Santa Monica, CA				●			Drinking Water	July 1998 to April 1999	Pilot-scale testing of Advanced Oxidation Processes (AOP) to treat MTBE and TBA in drinking water
Lacrosse, KS		●		●			Drinking Water	Ongoing, data from 1997 to September 1999	Use of air stripping to treat MTBE in drinking water
Rockaway, NJ	●			●			Drinking Water	Ongoing, data from 1980 to July 2000	Use of air stripping and GAC to treat MTBE in drinking water

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	MTBE	Metals	Radionuclides			
Pump and Treat									
Marine Corps Base, OU 1 and 2, Camp Lejeune, NC	●	●			●		Groundwater	Ongoing, data from January 1995 to March 1999	Use of pump and treat system to remediate groundwater contaminated with organics and metals
Marine Corps Base, Campbell Street Fuel Farm, Camp Lejeune, NC		●	●				Groundwater	Ongoing, data from 1996 to May 1999	Use of pump and treat system to remediate BTEX and SVOC groundwater contamination at three sites
Naval Air Station, Brunswick, Eastern Groundwater Plume, ME	●						Groundwater	Ongoing, data from May 1995 to May 1999	Use of pump and treat to treat groundwater contaminated with chlorinated VOCs
Ott/Story/Cordova Superfund Site, North Muskegon, MI	●		●		●		Groundwater (1.1 billion gallons)	Ongoing, data available from February 1996 to October 2000	Pump and treat of a multi-aquifer site contaminated with chlorinated and non-chlorinated VOCs and SVOCs
***In Situ* Groundwater Treatment**									
Brownfield Site, Chattanooga, TN (specific site name not identified) (Bioremediation)		●		●			Groundwater	Ongoing, data from January to December 1999	Use of *in situ* bioremediation to treat MTBE in groundwater
Butler Cleaners, Jacksonville, FL (Chemical Oxidation (KMnO4))	●						Groundwater	Not provided	Use of in situ oxidation with potassium permanganate to treat chlorinated solvents in groundwater at a dry cleaning site
Camp Lejeune Marine Corps Base, Bldg 25, Camp Lejeune, NC (*In Situ* Flushing (SEAR and PITT))	●						Groundwater	Not provided	Use of surfactant injection to treat chlorinated solvents in groundwater at a dry cleaning site
Contemporary Cleaners, Orlando. FL (Bioremediation (HRC))	●						Groundwater	Not provided	Use of Hydrogen Release Compound (HRC) to treat chlorinated solvents in groundwater at a dry cleaning site

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants* Chlorinated Solvents	 BTEX and/or TPH	 Pesticides/Herbicides	 MTBE	 Metals	 Radionuclides	Media (Quantity Treated)	Project Duration	Highlights
Cordray's Grocery, Ravenel, SC (Bioremediation (ORC))		●		●			Groundwater	April 1998 to July 2000	Use of *in situ* bioremediation using ORC$^{®}$ to treat MTBE in groundwater
Eaddy Brothers, Hemingway, SC (Air Sparging/SVE)		●		●			Groundwater	Ongoing, data from July 1999 to August 2000	Use of air sparging/soil vapor extraction to treat MTBE in soil and groundwater
Eight Service Stations, MD (specific sites not identified) (Multi-Phase Extraction)		●		●			Groundwater	1990 to 1997	Use of Soil Vapor Extraction and Groundwater Extraction to treat soil and groundwater contaminated with MTBE and BTEX
Fernald Environmental Management Project, OH (*In Situ* Flushing)					●		Groundwater	September 1998 to September 1999	Field demonstration of *in situ* flushing as an enhancement to pump and treat technology
Former Nu Look One Hour Cleaners, Coral Springs, FL (Air Sparging/Recirculation Well)	●						Groundwater	Not provided	Use of proprietary in well stripping technology to treat chlorinated solvents in groundwater at a dry cleaning site
Former Sages Dry Cleaners, Jacksonville, FL (*In Situ* Flushing (Ethanol Co-Solvent))	●						Groundwater	Not provided	Use of surfactant injection to treat chlorinated solvents in groundwater at a dry cleaning site
Four Service Stations (specific site names not identified) (Air Sparging)		●		●			Groundwater	1993 to 1995	Air sparging used to treat MTBE in groundwater
Gas Station, Cheshire, CT (specific site name not identified) (Bioremediation)		●		●			Groundwater	October 1997 to March 1999	Use of *in situ* bioremediation to treat MTBE in groundwater
Hayden Island Cleaners, Portland, OR (Bioremediation (HRC))	●						Groundwater	Not provided	Use of Hydrogen Release Compound (HRC) to treat chlorinated solvents in groundwater at a dry cleaning site
Johannsen Cleaners, Lebanon, OR (Multi-Phase Extraction)	●						Groundwater	Not provided	Use of multi-phase extraction to treat chlorinated solvents in groundwater at a dry cleaning site
Lawrence Livermore National Laboratory, CA (Bioremediation)				●			Groundwater	Not provided	Research on microbial organisms to degrade MTBE in soil and groundwater

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*: Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	MTBE	Metals	Radionuclides	Media (Quantity Treated)	Project Duration	Highlights
Louisiana Army Ammunition Plant, LA (Monitored Natural Attenuation)							Groundwater	Not provided	Field demonstration of MNA for remediation of explosives
Miamisburg, OH (Air Sparging/SVE)	●						Groundwater	Ongoing, data from December 1997 to May 2000	Full-scale treatment of chlorinated solvents using air sparging and soil vapor extraction
Monticello Mill Tailings Site, Monticello, UT (Permeable Reactive Barrier)					●		Groundwater	June 1999	Demonstration of permeable reactive barrier to treat heavy metals in groundwater
Multiple Sites (Monitored Natural Attenuation of Chlorinated Solvents)	●						Groundwater	July 1993 to August 1999	Field demonstrations of monitored natural attenuation for chlorinated solvents in groundwater at multiple Air Force sites
Multiple Sites (Monitored Natural Attenuation of Petroleum Hydrocarbons)		●					Groundwater	July 1993 to December 1998	Field demonstrations of monitored natural attenuation for fuel hydrocarbons in groundwater at multiple Air Force sites
Multiple Sites (Bioslurping)		●					Groundwater	Not provided	Field demonstrations of bioslurping of LNAPL at multiple Air Force sites
Naval Air Station, Pensacola, FL (*In Situ* Oxidation)	●						Groundwater	November 1998 to May 1999	Use of Fenton's Reagent to remediate chlorinated solvents in groundwater
Naval Submarine Base, Kings Bay, GA (*In Situ* Oxidation)	●						Groundwater	February 1999	Use of Fenton's Reagent to remediate chlorinated solvents in groundwater
Scotchman #94, Florence, SC (Air Sparging, Pump and Treat)		●		●			Groundwater	Ongoing, data from April 1998 to March 2000	Use of multiphase extraction and air sparging/soil vapor extraction to treat MTBE in soil and groundwater
Service Station, CA (specific site name not identified) (Bioremediation (ORC))		●		●			Groundwater	Not provided	Use of *in situ* Bioremediation using Oxygen Release Compound (ORC$^{\circledR}$) to treat MTBE in groundwater
Service Station, Lake Geneva, WI (specific site name not identified) (Bioremediation (ORC))		●		●			Groundwater	Not provided	Use of *in situ* bioremediation using ORC$^{\circledR}$ to treat MTBE in groundwater

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	MTBE	Metals	Radionuclides			
South Beach Marine, Hilton Head, SC (Bioremediation)		●		●			Groundwater	Ongoing, data from February 1999 to September 2000	Use of *in situ* bioremediation to treat MTBE in groundwater
South Prudence Bay Island Park, T-Dock Site, Portsmouth, RI (Biosparging)		●					Groundwater	October 1997 to February 2000	Use of biosparging to treat BTEX-contaminated groundwater at a relatively remote site without collecting or discharging treated water
Sparks Solvents/Fuel Site, Sparks, NV (Multi-Phase Extraction)	●	●		●			Groundwater	Ongoing, data from 1995 to August 1997	Use of multiphase extraction using fluidized bed reactor and granular activated carbon to treat MTBE in groundwater
Specific site name not identified (Bioremediation)				●			Groundwater	Not provided	Bench-scale testing of the Butane Biostimulation Technologies^{TM} process to treat MTBE in groundwater
U.S. Navy Construction Battalion Center, Port Hueneme, CA (Bioremediation)				●			Groundwater	April to August 1998	Laboratory and field testing of *in situ* bioremediation using MC-100 to treat MTBE in groundwater
Vandenberg Air Force Base, Lompoc, CA (Bioremediation)				●			Groundwater	Ongoing, data from 1999	Use of *in situ* bioremediation to treat MTBE in groundwater
Containment									
Dover Air Force Base, Groundwater Remediation Field Laboratory National Test Site, Dover DE (Vertical Engineered Barrier)							Groundwater	October 1996 to September 1998	Demonstration of vertical engineered barrier using thin diaphragm walls
Sandia National Laboratory, Albuquerque, NM (Cap)							Soil	July 1995 to July 2000	Field demonstration of alternative landfill covers

* 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
Other *In Situ* Soil Treatment					
Alameda Point, CA (Electrokinetics)	$194,291	45 yd^3	Not provided	D - $4,318/$yd^3$; P - $90/$yd^3$	Not provided
Portsmouth Gaseous Diffusion Plant, X-231A Site, Piketon, OH (Hydraulic Fracturing)	$1,258,700	Not provided	Not provided	Not provided	Working within a radiation zone and use of reactive agents
Incineration					
Drake Chemical Superfund Site, Operable Unit 3, Lock Haven, PA (Rotary Kiln Incineration)	$92,930,000	273,509 tons	Not provided	$340/ton	Not provided
Thermal Desorption					
Metaltec/Aerosystems Superfund Site, Franklin Borough, NJ (Thermal Desorption)	$998,238	4,215 yd^3	Not provided	$237/$yd^3$	Not provided
New Bedford Harbor Superfund Site, New Bedford, MA (Thermal Desorption)	Not provided	Not provided	Not provided	P - $617/ton	Not provided
Reich Farm, Pleasant Plains, NJ (Thermal Desorption)	$2,205,000	14,836 yd^3	Not provided	$147/$yd^3$	Not provided
Rocky Flats Environmental Technology Site, Mound Site, Golden, CO (Thermal Desorption)	Not provided	724.5 yd^3	Not provided	Not provided	Not provided
Sarney Farm, Amenia, NY (Thermal Desorption)	$1,932,300	10,514 tons	Not provided	$184/ton	Local permit constraints limited operation to daylight hours
Other *Ex Situ* Soil Treatment					
Brookhaven National Laboratory, NY (Physical Separation/Segmented Gate System)	Not provided	625 yd^3	Not provided	$78/$yd^3$	Not provided
Idaho National Environmental and Engineering Laboratory (INEEL), ID (Physical Separation/Segmented Gate System)	Not provided	442 yd^3	Not provided	Not provided	Not provided
Massachusetts Military Reservation, Training Range and Impact Area, Cape Cod, MA (Solidification/Stabilization)	$3,500,000	23,168 yd^3	Not provided	$151/$yd^3$	*In situ* S/S treatment was used when possible as alternative to *ex situ S/S* treatment
New Bedford Harbor Superfund Site, New Bedford, MA (Solidification/Stabilization)	Not provided	Not provided	Not provided	Not provided	Not provided
New Bedford Harbor Superfund Site, New Bedford, MA (Solvent Extraction)	Not provided	Not provided	Not provided	P - $721/ton	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
New Bedford Harbor Superfund Site, New Bedford, MA (Vitrification)	Not provided	Not provided	Not provided	P - $1,149/ton	Not provided
Stauffer Chemical Company, Tampa, FL (Composting)	Not provided	Not provided	Not provided	P - $132/yd[3]	Not provided
Drinking Water Treatment					
Charnock Wellfield, Santa Monica, CA	Not provided	Not provided	Not provided	P - $1.50 to $1.75/1,000 gallons of treated water	Not provided
Lacrosse, KS	C - $185,000 AO - $30,000	Not provided	Not provided	Not provided	Not provided
Rockaway, NJ	C - $575,000 AO - $300,000	Not provided	Not provided	Not provided	Not provided
Pump and Treat					
Marine Corps Base, OU 1 and 2, Camp Lejeune, NC	OU 1 AO - 148,000 OU 2 C - $4,660,000 AO - $438,000	Not provided	OU 1 - 12 lbs OU 2 - 40,000 lbs	OU 1 $28,277/lb removed OU 2 $49/lb removed	OU 1 had removed relatively small amount of contaminant and was operating at <9% of design
Marine Corps Base, Campbell Street Fuel Farm, Camp Lejeune, NC	C - $507,395 AO - $180,000	Not provided	3.5 lbs	$95,000/lb removed	Relatively small amount of contaminant removed
Naval Air Station, Brunswick, Eastern Groundwater Plume, ME	C - $4,246,319 AO - $1,144,031	Not provided	Not provided	Initial - $11,000/lb removed Most Recent 8 Months - $6,200/lb removed	System designed to treat water from two areas, but only one area actually treated
Ott/Story/Cordova Superfund Site, North Muskegon, MI	$32,123,500	1.1 billion gallons	Not provided	$30/1,000 gallons treated	Not provided
***In Situ* Groundwater Treatment**					
Brownfield Site, Chattanooga, TN (specific site name not identified) (Bioremediation)	AO - $48,000	Not provided	Not provided	Not provided	Not provided
Butler Cleaners, Jacksonville, FL (Chemical Oxidation ($KMnO_4$))	C - $230,000 AO - $120,000	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
Camp Lejeune Marine Corps Base, Bldg 25, Camp Lejeune, NC (*In Situ* Flushing (SEAR and PITT))	Not provided	Not provided	Not provided	Not provided	Not provided
Contemporary Cleaners, Orlando. FL (Bioremediation (HRC))	$127,000	Not provided	Not provided	Not provided	Not provided
Cordray's Grocery, Ravenel, SC (Bioremediation (ORC))	$21,000	Not provided	Not provided	Not provided	Cleanup conducted as a fixed-price, lump sum contract
Eaddy Brothers, Hemingway, SC (Air Sparging/SVE)	$197,515	Not provided	Not provided	Not provided	Cleanup conducted as a fixed-price, lump sum contract
Eight Service Stations, MD (specific sites not identified) (Multi-Phase Extraction)	Not provided	Not provided	Not provided	Not provided	Not provided
Fernald Environmental Management Project, OH (*In Situ* Flushing)	Not provided	Not provided	Not provided	Not provided	Not provided
Former Nu Look One Hour Cleaners, Coral Springs, FL (Air Sparging/Recirculation Well)	$193,000	Not provided	Not provided	Not provided	Not provided
Former Sages Dry Cleaners, Jacksonville, FL (*In Situ* Flushing (Ethanol Co-Solvent))	$440,000	Not provided	Not provided	Not provided	Not provided
Four Service Stations (specific site names not identified) (Air Sparging)	Not provided	Not provided	Not provided	Not provided	Not provided
Gas Station, Cheshire, CT (specific site name not identified) (Bioremediation)	Not provided	Not provided	Not provided	Not provided	Not provided
Hayden Island Cleaners, Portland, OR (Bioremediation (HRC))	$46,000	Not provided	Not provided	Not provided	Not provided
Johannsen Cleaners, Lebanon, OR (Multi-Phase Extraction)	$230,000	Not provided	Not provided	Not provided	Not provided
Lawrence Livermore National Laboratory, CA (Bioremediation)	Not provided	Not provided	Not provided	Not provided	Not provided
Louisiana Army Ammunition Plant, LA (Monitored Natural Attenuation)	$4,000,000	Not provided	Not provided	Not provided	Cost included site characterization, monitoring, and modeling, and development of biomarker techniques
Miamisburg, OH (Air Sparging/SVE)	$1,439,039	Not provided	Not provided	$420/lb removed	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
Monticello Mill Tailings Site, Monticello, UT (Permeable Reactive Barrier)	$1,196,000	Not provided	Not provided	Not provided	Not provided
Multiple Sites (Monitored Natural Attenuation of Chlorinated Solvents)	$122,000/site (average)	Not provided	Not provided	P - long-term monitoring cost of $22,800	Not provided
Multiple Sites (Monitored Natural Attenuation of Petroleum Hydrocarbons)	$125,000/site (average)	Not provided	Not provided	P - long-term monitoring cost of 192,000	Not provided
Multiple Sites (Bioslurping)	Not provided	Not provided	Not provided	$56/gal recovered	Not provided
Naval Air Station, Pensacola, FL (*In Situ* Oxidation)	T - $250,000 M - $100,000/yr	Not provided	Not provided	Not provided	Not provided
Naval Submarine Base, Kings Bay, GA (*In Situ* Oxidation)	$1,050,000 (first two phases)	Not provided	Not provided	Not provided	Not provided
Scotchman #94, Florence, SC (Air Sparging, Pump and Treat)	$383,000	Not provided	Not provided	Not provided	Cleanup conducted as a fixed-price, lump sum contract
Service Station, CA (specific site name not identified) (Bioremediation (ORC))	Not provided	Not provided	Not provided	Not provided	Not provided
Service Station, Lake Geneva, WI (specific site name not identified) (Bioremediation (ORC))	Not provided	Not provided	Not provided	Not provided	Not provided
South Beach Marine, Hilton Head, SC (Bioremediation)	$63,500	Not provided	Not provided	Not provided	Cleanup conducted as a fixed-price, lump sum contract
South Prudence Bay Island Park, T-Dock Site, Portsmouth, RI (Biosparging)	$280,946	Not provided	Not provided	Not provided	Not provided
Sparks Solvents/Fuel Site, Sparks, NV (Multi-Phase Extraction)	Not provided	Not provided	Not provided	Not provided	Not provided
Specific site name not identified (Bioremediation)	Not provided	Not provided	Not provided	Not provided	Not provided
U.S. Navy Construction Battalion Center, Port Hueneme, CA (Bioremediation)	Not provided	Not provided	Not provided	P - $150,000	Not provided
Vandenberg Air Force Base, Lompoc, CA (Bioremediation)	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
Containment					
Dover Air Force Base, Groundwater Remediation Field Laboratory National Test Site, Dover DE (Vertical Engineered Barrier)	Not provided	Not provided	Not provided	P - ranged from \$6.71 to \$8.21/ft^2	Not provided
Sandia National Laboratory, Albuquerque, NM (Cap)	Not provided	Not provided	Not provided	Ranged from \$51.40/m^2 to \$157.54/m^2	Type of covers included RCRA Subtitles C and D, GCL, Capillary, Anisotropic, and ET

[1] Actual full-scale costs are reported unless otherwise noted.
[2] Cost abbreviation: AO = annual operation and maintenance (O&M) costs, C = capital costs, M = monitoring costs, D = Demonstration-scale, P = Projected full scale.

IN SITU SOIL TREATMENT ABSTRACTS

Electrokinetic Remediation at Alameda Point, Alameda, California

Site Name:
Alameda Point (formerly Naval Air Station Alameda)

Location:
Alameda, CA

Period of Operation:
December 1997 - June 1998

Cleanup Authority:
Not provided

EPA Contact:
Mike Gill
U.S. EPA Region 9
Phone: (415) 744-2385
E-mail: gill.michael@epa.gov

Purpose/Significance of Application:
Field demonstration of electrokinetic treatment of chromium in soil

Cleanup Type:
Field Demonstration

Contaminants:
Heavy Metals (Chromium)
- Chromium concentrations were as high as 2,060 mg/kg

Waste Source:
Electroplating operations

Technology Vendor:
Geokinetics International Inc.
Berkeley, CA

BADCAT Contact:
Robin Truitt
BADCAT ETP Coordinator
Phone: (510) 986-0303
E-mail: rctruitt@aol.com

Navy Contacts:
Andrew Drucker
Phone: (805) 982-4847
E-mail: druckeras@nfesc.navy.mil

Michael Bloom
Phone: (619) 532-0967
E-mail: bloomms@navfac.navy.mil

Technology:
Electrokinetics
- Demonstration system used 15 electrodes - three rows of electrodes positioned one meter apart, with each row consisting of five electrodes spaced every two meters
- Electrodes were installed 2.4 meters bgs for a total soil volume of 38.4 cubic meters
- An acidic solution was maintained at a pH of 4 - 5 in the electrode cells, and solution was removed for processing and recovery above-ground

Type/Quantity of Media Treated:
Soil
- 38.4 cubic meters of alkaline soil

Regulatory Requirements/Cleanup Goals:
- Reduce chromium concentrations in soil to 30 mg/kg (EPA Region 9's preliminary remediation goal for residential use)

Results:
- In most soil layers, the system met the cleanup goal, however, in the most contaminated layer of soil (the interface between soil and concrete), the system did not meet the cleanup goal of 30 mg/kg of chromium in soil
- Electrokinetics removed 12% of the total chromium based on pre- and post-treated soil data, and only 1% based on total chromium recovered in the electrode solution
- During the demonstration, the water table dropped below design specifications and bentonite seals were used to maintain the electrode solution; this modification was projected to have decreased system performance by as much as 50 percent

Costs:
- The demonstration had a cost of $194,291, or $4,318/cubic yard, for vendor-supplied services
- It was projected that a full-scale system would have treatment costs of $90/cubic yard

Electrokinetic Remediation at Alameda Point, Alameda, California

Description:
Alameda Point had a former aircraft rework facility plating shop that operated from 1942 to 1990. During plating operations, chromium leaked into the soil beneath the shop. The Navy, in coordination with the Bay Area Defense Conversion Action Team (BADCAT) Environmental Technology Partnership (ETP), conducted a demonstration of electrokinetics at this site. The BADCAT is a public-private partnership of several organizations in the San Francisco area, including the Bay Area Economic Forum, Bay Area Regional Technology Alliance, California EPA, San Francisco State University, EPA, and Navy.

Electrokinetic remediation was performed for four months using 38.4 cubic meters of soil. Treatment removed 12% of the total chromium based on pre- and post-treated soil data, and only 1% based on total chromium recovered in the electrode solution. In most soil layers, the system met the cleanup goal, however, in the most contaminated layer of soil (the interface between soil and concrete), the system did not meet the cleanup goal. The demonstration had a cost of $194,291, or $4,318/cubic yard, for vendor-supplied services. It was projected that a full-scale system would have treatment costs of $90/cubic yard

Hydraulic Fracturing of Low Permeability Media at Portsmouth Gaseous Diffusion Plant, X-231A, Piketon, Ohio

Site Name:
Portsmouth Gaseous Diffusion Plant, X-231A

Location:
Piketon, OH

Period of Operation:
1996 to 1998

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Field demonstration of hydraulic fracturing with four types of remediation technologies

Cleanup Type:
Field Demonstration

Contaminants:
Chlorinated Solvents
- Trichloroethene (TCE) and related halocarbons at concentrations as high as 100 mg/kg

Waste Source:
Disposal of waste oils and degreasing solvents

Technical Contacts:
Robert L. Siegrist
Colorado School of Mines
Phone: (303) 273-3490

William W. Slack
FRx, Inc.
Phone: (513) 469-6040

Management Contacts:
Tom Houk
Bechtel Jacobs Company LLC
Phone: (740) 897-6502

Jim Wright
DOE SRS/SCFA
Phone: (803) 725-5608

Technology:
Hydraulic Fracturing
- Fractures were created by pushing a 2-inch steel casing and PVC drive point into the subsurface; dislodging the drive point an additional 1-4 inches, cutting a horizontal notch into the soil, pressurizing the notch with injected fluid, and propagating the fracture
- Remediation technologies were evaluated in four test cells with hydraulic fractures: Cell A - steam injection; Cell B - hot air injection; Cell C - iron metal permeable reactive barrier; and Cell D - potassium permanganate oxidation
- Cells A and B (hot fluid injection) were operated with 60 days in Fall 1996 and 45 days in Summer 1997; Cells C and D (reactive barriers) were operated passively during a two-year period
- Each treatment cell had dimensions of 45 ft length, 45 ft width, and 16 ft depth

Type/Quantity of Media Treated:
Soil and Groundwater
- Silty clay soils; depth to groundwater was 11.5 ft bgs, with soil water content near saturation almost to ground surface
- Soil pH 4-5; Eh 200 mV

Regulatory Requirements/Cleanup Goals:
- Evaluate the effectiveness of hydraulic fracturing with four remediation technologies
- No specific cleanup goals were identified

Results:
- Four to five fractures were created in each cell (total of more than 25 fractures) at depths from 4-18 ft bgs and at spacings as little as 2-3 ft
- For Cell B, hot air injection increased the rate of contaminants removed by volatilization, with off-gas containing more than 800 ppmv of TCE and up to 17% methane; in Cell A, a highly heterogeneous distribution of contaminant mass and low levels of contaminants precluded a thorough evaluation of process efficiency
- For Cell C, the iron proppant remained active (30-40% initial degradation of TCE) for up to 27 months after placement, but with little effect to surrounding soil
- For Cell D, the permanganate was more active (>99% degradation of TCE within 2 hours) and created zones of reactive soil that continued to grow away from the fracture over a 27 month period

Hydraulic Fracturing of Low Permeability Media at Portsmouth Gaseous Diffusion Plant, X-231A, Piketon, Ohio

Costs:

- The actual costs for the demonstration were $1,258,700, including $715,900 (Phase 1 operation), $76,400 (Phase 2 operation), $157,100 (Pre-demonstration site characterization), and $102,300 (project management)
- Costs for sand-propped fractures generally range from $850 to $1,500 per fracture; costs at this site were higher due to working within a radiation zone and higher costs for reactive agents

Description:

The Portsmouth Gaseous Diffusion Plant (PORTS) is located approximately 80 miles south of Columbus, in south-central Ohio. The industrialized portion of PORTS is 1,000 acres of a 3,714 acre DOE reservation. PORTS was constructed between 1952 and 1956 and has operated since 1955 enriching uranium for electrical power generation. The X-231A unit is located in the southeastern portion of the PORTS site and consists of an old waste oil biodegradation site. The unit, with an area of 950 ft by 225 ft, was reportedly used for the treatment and disposal of waste oils and degreasing solvents.

A field demonstration of hydraulic fracturing was conducted in the southeastern portion of the X-231A unit from 1996 to 1998. The demonstration involved construction of four test cells, with each cell testing hydraulic fracturing in conjunction with a different remediation technology - steam injection, hot air injection, iron PRB, and potassium permanganate. Four to five fractures were created in each cell (total of more than 25 fractures) at depths from 4-18 ft bgs and at spacings as little as 2-3 ft. The passive remediation technologies appeared to be more effective than those using fluid injection (steam or hot air). Of the two passive technologies, permanganate appeared to be more effective than iron.

EX SITU SOIL TREATMENT ABSTRACTS

Incineration at Drake Chemical Superfund Site, Operable Unit 3, Lock Haven, Pennsylvania

Site Name:
Drake Chemical Superfund (DCS) Site, Operable Unit 3

Location:
Lock Haven, Pennsylvania

Period of Operation:
- Trial Burn: 1/25/97 to 2/4/97
- Full-Scale Operation: 3/4/98 to 4/22/99

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

Vendor:
Mr. Frederick Santucci
OHM Remediation Services
180 Myrtle Street
Lock Haven, PA 17745
(570) 748-4102
santucci@ohm.com

Purpose/Significance of Application:
Remediation designed to provide permanent destruction of soil contaminants; no long-term waste management requirements following on-site backfill of incinerator ash

Cleanup Type:
Full-scale Remedial Action

Contaminants:
- 470 to 1,500,000 mg/kg b-Naphthylamine
- 3.8 to 8,200 mg/kg Fenac
- Halogenated and non-halogentated VOCs and SVOCs detected in soil

Waste Source:
Two lined and two unlined waste management lagoons; disposal of drums of chemical waste, chemical sludge and demolition debris on the ground surface and in the shallow subsurface

Project Management:
Mr. William Werntges
USACE, Harrisburg Area Office
CENAB-COF-HA285
18th Street
DDRE, Bldg S-285
Newcumberland, PA 17070
(717) 782-8750
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Mr. Mike Ogden
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CENAB-COF-HA285
18th Street
DDRE, Bldg S-285
Newcumberland, PA 17070
(717) 782-3750
m.odgen@usace.army.mil

Regulatory Contacts
Mr. Gregg Crystal
U.S. EPA Region
31650 Arch Street
Philadelphia, PA 19103-2029
(215) 814-3207
crystall.gregg@epa.gov

Mr. Michael Welch
Pennsylvania Department of Environmental Protection
208 West 3rd Street, Suite 101
Williamsport, PA 17701-6448
(570) 321-6518
welch.michael@a1.pader.gov

Technology:
On-Site Incineration
- 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 1599 ˚F and the SCC operated above 1801 ˚F
- Hot gases exiting the SCC passed through an evaporative cooler, a baghouse, a venturi quench unit, and a caustic scrubber.
- Excavated soil was dried and screened to remove oversized organic and inorganic debris.
- Excavated soil and shredded combustible material were fed to the incinerator.
- 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:
- 273,509 tons (180,296 cubic yards) of contaminated soil
- Moisture Content: 17.6% average, range of 10 to 25.5%
- BTU Value: 274 Btu/lb

Incineration at Drake Chemical Superfund Site, Operable Unit 3, Lock Haven, Pennsylvania

Regulatory Requirements/Cleanup Goals:
- Destruction and Removal Efficiency (DRE) of 99.99% for POHC.
- Treated soil objectives were 55 mg/kg for b-Naphthylamine and 1,000 mg/kg for Fenac.
- Treated soil and fly ash with TCLP concentrations in excess 25 times the drinking water standard for any one of eight metals were stabilized.
- Air emission requirements included control of metals, hydrogen chloride, total dioxins and furans, carbon monoxide, nitrous oxides, and particulate matter in the stack gas.

Results:
- Sampling of treated soil indicated that the cleanup goals were met. Three percent of the soil required re-treatment to achieve cleanup levels.
- Two batches of fly ash required stabilization prior to on-site backfill
- Emission data from the trial burn and full-scale operations indicated that all emissions standards were met.

Costs:
- The total cost for this project was $112,381,000, with a technology-specific cost of $92,930,000.
- The technology-specific unit cost was $340 per ton of soil treated.

Description:
The DCS Site included a chemical manufacturing facility that operated from 1951 to 1982, producing chemical intermediates used in dye, cosmetic, textile, pharmaceutical, pesticide and herbicide manufacturing. Two lined wastewater treatment lagoons, a dry unlined sludge lagoon, and an unlined leachate lagoon were constructed at the site during the late 1950s, probably for use as waste impoundments. Drums of chemical waste, chemical sludge, and demolition debris were disposed on the ground surface and in the shallow subsurface at the site.

Site soil and chemical sludge were contaminated with VOCs, SVOCs including b-naphthylamine, the herbicide Fenac, and metals. These compounds were detected throughout the site regardless of sampling depth. A ROD was signed in September 1988, specifying on-site incineration as the remedial technology for addressing soil contamination at the site. Contaminated soil/sludge/sediment and groundwater were identified as Operable Unit (OU) 3.

Site work for construction of the incinerator commenced in April 1995. Incinerator shake down and a clean burn were conducted in January 1996. The incinerator was then shut down until September 1996 due to a lawsuit filed to stop the remediation project. System optimization and preliminary testing were conducted in the Fall of 1996. The trial burn and risk burns were conducted in January and February 1997. Following approval of the test results, the incinerator was put into full-scale operation in March 1998. All site soil was excavated down to the water table (about 15 feet below ground surface) and treated. The total area of the DCS Site is 9.6 acres. 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. Treatment was completed in April 1999.

Thermal Desorption at the Metaltec Superfund Site, Franklin Borough, New Jersey

Site Name:
Metaltec Superfund Site

Location:
Franklin Borough, New Jersey

Period of Operation:
December 1994 - January 1995

Cleanup Authority:
CERCLA
- ROD issued June 30, 1986

EPA Remedial Project Manager:
Daniel Weissman
U.S. EPA Region 2
290 Broadway, 19th Floor
New York, NY 10007
Telephone: (212) 637-4384
Fax: (212) 637-4429
E-mail: weissman.daniel@epa.gov

Purpose/Significance of Application:
Use of thermal desorption to treat soil contaminated with chlorinated volatile organic compounds

Cleanup Type:
Remedial

Contaminants:
Chlorinated Volatile Organic Compounds (VOCs) and Heavy Metals
- Maximum concentrations in soil were trichloroethene (TCE) - 7,600 mg/kg and 1,2-dichloroethene (DCE) - 6,600 mg/kg

Waste Source:
Disposal in lagoon; spills

USACE Contact:
Ronny Hwee
USACE
214 State Highway 18
East Brunswick, NJ 08816
Telephone: (973) 674-1598
Fax: (973) 674-1668

Vendor:
Mark A. Fleri, P.E.
Project Manager
Williams Environmental Services, Inc.
2075 West Park Place
Stone Mountain, GA 30087
Telephone: (800) 892-0992
Fax: (770) 879-4831
E-mail: mfleri@wmsgrpintl.com

Technology:
Thermal Desorption - A low temperature enhanced volatilization system provided by Williams Environmental was used to treat soil at the site
- The desorber was a direct-heated, rotary dryer equipped with a gas burner and operated using countercurrent flow under negative pressure
- Soil was heated in the desorber to a temperature of 750°F for 15-20 minutes
- Emission controls included a baghouse, thermal oxidizer, quench, and scrubber

Type/Quantity of Media Treated:
Soil
- 4,215 yd^3 treated
- Soil was characterized as stiff sandy clays; silty, sandy clays; and sands and gravel
- Moisture content was <20%

Regulatory Requirements/Cleanup Goals:
- The ROD specified the following cleanup goals: vinyl chloride - 33 mg/kg; tetrachloroethene (PCE) - 0.05 mg/kg; trans-1,2-DCE - 33 mg/kg; TCE - 5.6 mg/kg; chloroform - 5.6 mg/kg; 1,1,1-trichloroethane - 0.41 mg/kg; and 1,1-dichloroethane - 7.2 mg/kg
- The ROD required that treated soil that failed to meet the TCLP metals requirements be shipped off-site for stabilization and disposal at an approved RCRA permitted facility.
- Air emissions standards were specified in a NJDEP air permit, including a destruction and removal efficiency (DRE) for the thermal oxidizer of 99.99%

Results:
- All soil met the cleanup goals on the first pass through the desorber and no soil was retreated. Data on the concentration of individual constituents in the treated soil were not provided
- A performance test was performed to demonstrate compliance with soil cleanup requirements and air emissions standards, and to establish operating parameters for the remainder of the project. During the performance test (three runs), all treated soil samples were below the detection limit of 0.002 mg/kg for PCE and TCE. All emission results met the test objectives with the exception of lead and sulfur oxides, which were deemed acceptable by the USACE and EPA.

Thermal Desorption at the Metaltec Superfund Site, Franklin Borough, New Jersey

Costs:

- The total cost for treatment of 4,215 cubic yards of contaminated soil at this site was $998,238. This included costs for technology mobilization, setup, and demobilization, planning and preparation, and equipment and appurtenances.
- The calculated unit cost for this application was $237 per cubic yard of soil (based on a total of 4,215 cubic yards of soil treated).

Description:

From 1965 to the mid 1980s, the Metaltec Corporation, a subsidiary of Aerosystems Technology Corporation, operated a metal-plating facility in Franklin Borough, Sussex County, New Jersey. The facility produced assorted metal parts including metal ballpoint pen casings, paint spray guns, and lipstick cases. During that time, wastewater from the plating operations was discharged on-site to an unlined wastewater lagoon. In addition, wastes were spilled and dumped in various locations at the facility. The unlined wastewater lagoon was abandoned sometime in the 1980s and subsequently backfilled by the owners. In 1980, the New Jersey Department of Environmental Protection (NJDEP) conducted several investigations of the former wastewater lagoon and a pile of green material that was stored at the site, and found that soil and groundwater in these areas were contaminated by VOCs and heavy metals. The site was placed on the National Priorities List (NPL) in September, 1983.

A thermal desorption system was used at the site to treat soil contaminated with VOCs. This system treated 4,215 yd^3 of contaminated soil to below cleanup goals in less than 2 months, with no soil requiring retreatment. According to the vendor, the thermal desorption system was operated at a 75% on-stream efficiency despite severe weather conditions. In addition, the vendor was able to maintain the contract-required schedule despite delays in the air permitting process. The vendor indicated that developing an active relationship with the community allowed operations to be extended from 12 hours/day to 24 hours/day, which was critical to maintaining the project schedule.

Thermal Desorption/Gas Phase Chemical Reduction at the New Bedford Harbor Superfund Site, New Bedford, Massachusetts

Site Name:
New Bedford Harbor Superfund Site

Location:
New Bedford, Massachusetts

Period of Operation:
November 1996

Cleanup Authority:
CERCLA
- ROD signed April 1990

Purpose/Significance of Application:
Demonstration of thermal desorption/gas phase chemical reduction to treat PCB-contaminated sediments

Cleanup Type:
Field demonstration

Contaminants:
PCBs
- Maximum concentrations in sediments of more than 200,000 mg/kg

Waste Source:
Discharge of polychlorinated biphenyl (PCB)-contaminated wastewater from electronics manufacturing

EPA RPM:
James M. Brown
U.S. EPA Region 1 (MC HBO)
1 Congress Street, Suite 1100
Boston, MA 02114-2023
Telephone: (617) 918-1308
E-mail: brown.jim@epa.gov

Technology Vendor:
Beth Kümmling
ELI Eco Logic International, Inc.
143 Dennis Street
Rockwood, Ontario N0B 2K0

Canada
Telephone: (519) 856-9591 (ext. 203)
Fax: (519) 856-9235
E-mail: kummlib@eco-logic-intl.com

Technology:
Thermal Desorption/Gas Phase Chemical Reduction (GPCR)
- Pilot-scale test of Eco Logic's GPCR process - thermal desorption followed by gas phase chemical reduction
- Three main components - a thermal reduction mill (TRM), a GPCR reactor, and a gas scrubbing and compression system
- TRM - operated with indirect heat, using a molten tin bath (heated by propane) to transfer heat to the sediments; volatilized organic compounds and steam were removed from the TRM using hydrogen sweep gas which was vented to the GPCR reactor
- GPCR reactor - operated in a hydrogen atmosphere at a minimum temperature of 900°C. As the gas passed through the reactor (typical residence time of 4 to 10 seconds), the organics were reduced to methane and hydrochloric acid, which were sent to the gas scrubber
- Gas scrubbing and compression system - two-stage caustic scrubbing system; scrubbed gas compressed and stored before being burned in the Excess Gas Burner prior to release to the atmosphere
- Pilot testing included acclimation runs to provide preliminary data for optimizing process conditions and performance verification runs to evaluate the process

Type/Quantity of Media Treated:
Sediment
- Fine sandy silt with some clay-sized particles present; some small shell fragments present
- Moisture content - 50% by weight

Regulatory Requirements/Cleanup Goals:
- Target goals for demonstration were 50 mg/kg for PCBs and the Toxicity Characteristic Leaching Procedure (TCLP) criteria for metals

Results:
- TRM reduced PCB concentrations to 28 to 77 mg/kg in treated sediment, with an average of 52 mg/kg; the PCB desorption efficiency ranged from 98.36 to 99.52%, with an average of 99.06%
- GPCR reactor achieved a PCB destruction efficiency ranging from 99.99972% to 100%
- TCLP metals concentrations in the treated sediment were below the regulatory criteria

Thermal Desorption/Gas Phase Chemical Reduction at the New Bedford Harbor Superfund Site, New Bedford, Massachusetts

Costs:

- Projected full-scale costs for thermal desorption/gas phase chemical reduction of sediments were $11,114,000, including $5,865,000 in capital costs and $5,249,000 in O&M costs.
- Projected full-scale costs were based on treating 18,000 tons of sediment, for a unit cost of $617 per ton

Description:

The New Bedford Harbor Superfund Site is located along the northwestern shore of Buzzards Bay in New Bedford Massachusetts, approximately 55 miles south of Boston. From the 1940s to 1978, PCB-contaminated wastewater from electronics manufacturing operations was discharged onto the shoreline and into the harbor. Site investigations determined that sediments were contaminated with PCBs and heavy metals. The site was listed on the National Priorities List in September 1983. The ROD for a five acre area known as the “Hot Spot area” included dredging of PCB-contaminated sediments followed by incineration. However, due to opposition to incineration, EPA postponed the incineration component of the Hot Spot remedy to explore alternative treatment technologies. EPA evaluated four technologies as possible alternatives to incineration - solvent extraction/dechlorination, vitrification, thermal desorption/gas phase chemical reduction, and solidification/stabilization. This report covers the pilot-scale test of a thermal desorption/gas phase chemical reduction process.

The pilot test was performed using Eco Logic’s GPCR process, which consisted of a TRM, a GPCR reactor, and a gas scrubbing and compression system. During the pilot test, the concentration of PCBs in the treated sediment from the TRM ranged from 28 to 77 mg/kg, with an average of 52 mg/kg. The TRM PCB desorption efficiency ranged from 98.36 to 99.52%, with an average of 99.06%. The PCB concentrations in treated sediment were higher than Eco Logic expected, and may be attributed to the treated sediment accumulating in the auger. The GPCR reactor achieved a destruction efficiency ranging from 99.99972% to 100% for PCBs and an average destruction efficiency for total dioxins and furans of 99.9923 and 99.99959, respectively. TCLP metals concentrations in the treated sediment were below the regulatory criteria. The pilot-scale TRM unit did not allow for the collection of isokinetic (flow representative) gas samples. The vendor concluded that the results of the pilot study can be used for a summary assessment of performance, but that additional data would be needed to draw definitive conclusions regarding dioxin and furan production and the concentrations of contaminants downstream of the TRM.

Thermal Desorption at the Reich Farm Superfund Site, Pleasant Plains, New Jersey

Site Name: Reich Farm Superfund Site	**Location:** Pleasant Plains, New Jersey
Period of Operation: November 1, 1994 to March 10, 1995	**Cleanup Authority:** CERCLA • ROD signed September 30, 1988
Purpose/Significance of Application: Thermal desorption treatment of soils contaminated with VOCs and SVOCs	**Cleanup Type:** Full scale
Contaminants: Volatile Organic Compounds (VOCs) and Semivolatile Organic Compounds (SVOCs)	**Waste Source:** Leaking drums and disposal of wastes in trenches
EPA Remedial Project Manager (RPM): Jonathan Gorin EPA Region 2 290 Broadway, 19th Floor New York, NY 10007 Telephone: (212) 637-4361 Fax: (212) 637-4429 E-mail: gorin.jonathan@epa.gov **PRP Project Lead:** Craig Wilger Union Carbide Technical Center P.O. Box 8361 South Charleston, WV 25303 Telephone: (304) 747-3707 Fax: (304) 747-3680 E-mail: wilgerca@ucarb.com **Vendor:** Shawn Todaro Vice President Four Seasons Environmental, Inc. 3107 South Elm Eugene Street Greensboro, North Carolina 27416 Telephone: (336) 273-2718 Fax: (336) 274-5798	**Technology:** Thermal Desorption • Low temperature volatilization system (LTVS) owned by Four Seasons Environmental, Inc. • Transportable thermal desorption unit mounted on a trailer; the desorber was 38 feet long and eight feet in diameter and had a maximum throughput of 45 tons/hour • The primary treatment unit was directly heated with a 50 million BTU/hr burner that used #2 fuel oil • Air pollution control equipment for the system included a multi-cyclone, thermal oxidizer, heat exchanger, dry scrubber, and baghouse • Residence time - 8 to 12 minutes; soil exit temperature - 650 to 750 °F
	Type/Quantity of Media Treated: Soil • 14,836 cubic yards • Primarily coarse sand with small amounts of clay and silt • Moisture Content - < 10%
Regulatory Requirements/Cleanup Goals: The soil cleanup levels specified in the ROD were 1 mg/kg for total VOCs and 10 mg/kg for total SVOCs	
Results: • All treated soil met the cleanup goals of 1 mg/kg for total VOCs and 10 mg/kg for total SVOCs, and was backfilled on site • No information was provided about the specific VOC and SVOC concentrations in the treated soil or whether any soil required retreatment prior to meeting the cleanup goals	
Costs: • The total project cost was $4,115,000, including $2,205,000 for the thermal treatment application and $1,910,000 in other project costs such as excavation sampling, soil excavation, and sheeting and shoring of the excavation • The unit cost for the thermal treatment application was $147 per cubic yard of soil treated	

Thermal Desorption at the Reich Farm Superfund Site, Pleasant Plains, New Jersey

Description:
The Reich Farm Superfund Site (Reich Farm) is a three acre site located in Pleasant Plains, New Jersey. In 1971, the site was leased by an independent waste hauler and used for a five-month period to dispose of 55-gallon drums containing organic solvents, still bottoms, residues, and other wastes. In December 1971, the owners of Reich Farm found 4,950 drums at the site (4,500 drums containing waste and 450 empty drums), along with several trenches that had been used for waste disposal. Labels indicated that the drums belonged to Union Carbide. Results of the Remedial Investigation showed that groundwater and subsurface soils at the site were contaminated with VOCs and SVOCs, and the site was listed on the National Priorities List in September 1983. A ROD for the site, signed in September 1988, specified excavation and on-site treatment using enhanced volatilization of soil.

The thermal treatment system used for this application was a transportable low temperature volatilization system (LTVS) owned by Four Seasons Environmental, Inc. The primary treatment unit was directly heated and had a maximum throughput of 45 tons/hour. From November 1, 1994 to March 10, 1995, 14,836 cubic yards of contaminated soil was treated using the LTVS. All treated soil met the cleanup goals of 1 mg/kg for total VOCs and 10 mg/kg for total SVOCs, and was backfilled on site. No information was provided about the specific VOC and SVOC concentrations in the treated soil or whether any soil required retreatment prior to meeting the cleanup goals.

Thermal Desorption at the Rocky Flats Environmental Technology Site, Golden, Colorado

Site Name:
Rocky Flats Environmental Technology Site; Mound Site

Location:
Golden, Colorado

Period of Operation:
July - August 1997

Cleanup Authority:
CERCLA
- DOE Final Action Memorandum 3/97

EPA Contact:
Tim Rehder
U.S. EPA Region 8
999 18th Street, Suite 500
Denver, CO 80202
Phone: (303) 312-6293
E-mail: rehder.timothy@epa.gov

Purpose/Significance of Application:
Thermal desorption of soil contaminated with halogenated volatile organic compounds

Cleanup Type:
Full scale

Contaminants:
Halogenated Volatile Organic Compounds (VOCs)
- Tetrachloroethene (PCE) was the primary VOC, with concentrations as high as 760 mg/kg
- Trichloroethene (TCE), carbon tetrachloride, and methylene chloride were not detected above their cleanup goals in any soil samples

Waste Source:
Burial of drums of waste

Site Contacts:
Norma Castaneda
U.S. DOE
Rocky Flats Field Office
10808 Highway 93, Unit A
Golden, CO 80403
Phone: (303) 966-4226
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SAIC
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Technology Vendor:
Ron Hill
McLaren Hart
9323 Stockport Place
Charlotte, NC 28273
Phone: (704) 587-0003
E-mail:
ronnie_hill@mclaren-hart.com

Technology:
Thermal Desorption
- The McLaren Hart IRV-150 Batch Thermal Desorption Unit was used, including four ovens
- Each oven is 8-feet wide by 18-feet long by 1.5-feet high, and includes two removable trays, with a capacity of 2.25 cubic yards of soil per tray
- The desorber was operated at 180oF and a soil residence time of 2.5 - 3.5 hours
- Off-gases were treated with HEPA filtration, condensation, and vapor-phase GAC
- Condensate was treated using chemical precipitation, microfiltration, neutralization, dewatering, ultraviolet/peroxide oxidation, ion exchange, and liquid-phase GAC adsorption

Type/Quantity of Media Treated:
Soil
- 724.5 cubic yards of soil from two groups: (1) above claystone/sandstone layer; and (2) weathered claystone/sandstone material
- Soil in first group consisted of clay (15-50%), silt (10-40%), sand (20-30%), and gravel (10-40%)
- Soil in second group consisted of clay (45-90%), silt (40-85%), and sand (5-55%)
- Moisture content of both groups ranged from 10-18%

Regulatory Requirements/Cleanup Goals:
- Cleanup goals for treatment of soil were identified for PCE (6.0 mg/kg), TCE (4.0 mg/kg), carbon tetrachloride (2.0 mg/kg), and methylene chloride (5.77 mg/kg)
- Based upon air dispersion modeling results, stack monitoring for radionuclides was not required

Results:
- Except for two batches, all treated soil samples met the cleanup goals on the first pass, with all results below detection limits
- The two batches that did not meet the treatment goal for PCE were re-treated met the goals after re-treatment

Thermal Desorption at the Rocky Flats Environmental Technology Site, Golden, Colorado

Costs:

- A total of $2,316,000 was expended for cleanup of this site, including $580,000 for planning and site preparation, $210,000 for project management, and $1,526,000 for excavation, treatment, waste disposition, and site restoration. Information about the portion of the $1,526,000 for excavation, treatment, waste disposition, and site restoration that was directly attributable to thermal treatment was not available. Therefore, a unit cost for treatment of contaminated soil was not calculated. DOE considers information about the amount expended for thermal desorption treatment confidential business information.

Description:

The U.S. Department of Energy (DOE) used the Rocky Flats Environmental Technology Site (RFETS) to fabricate components for nuclear weapons from 1951 to 1989. Hazardous mixed wastes generated from the associated machining operations were disposed at various locations at the site, including the Mound Site. Approximately 1,400 drums containing hazardous mixed waste, including uranium, beryllium, hydraulic oil, carbon tetrachloride and PCE were placed at the Mound Site between April 1954 and September 1958. These drums were covered with soil thus generating a "mound". Over time, contamination leaked from these drums into the surrounding soils and groundwater.

Thermal desorption technology was selected to treat contaminated soils from the Mound Site. A batch process design was selected based on the relatively small volume of soil to be treated, and a desire to minimize size reduction activities because of the presence of radionuclide contamination. This application included several enhancements to the McLaren Hart thermal treatment system, including use of trays to hold the soil instead of placing the soil directly into the ovens, and use of a preheater in the off gas treatment train between the condenser and the HEPA filters to raise the temperature of the off gas leaving the condenser above its dew point. Treated soil samples met the cleanup goals on the first pass, with results below detection limits for all but two batches. These two batches were re-treated and met the goals after re-treatment. Information was not available about the cost for thermal desorption treatment at this site.

Thermal Desorption at the Sarney Farm Superfund Site, Amenia, New York

Site Name:
Sarney Farm Superfund Site

Location:
Amenia, New York

Period of Operation:
August through December 1997

Cleanup Authority:
CERCLA
- ROD signed September 27, 1990

EPA Remedial Project Manager (RPM):
Kevin Willis
EPA Region 2
290 Broadway, 19th Floor
New York, NY 10007
Telephone: (212) 637-4252
Fax: (212) 637-3966
E-mail: willis.kevin@epa.gov

Purpose/Significance of Application:
Thermal desorption treatment of soils contaminated with VOCs

Cleanup Type:
Full scale

Contaminants:
Volatile Organic Compounds
- Seven contaminants of concern (COCs) were identified including 1,2-dichloroethane, 2-butanone, 4-methyl-2-pentanone, chloroform, toluene, trichloroethene, total xylenes

Waste Source:
Leaking drums and disposal of wastes in trenches

Vendor:
Mark A. Fleri, P.E.
Project Manager
Williams Environmental Services, Inc.
2075 West Park Place
Stone Mountain, GA 30087
Telephone: (800) 247-4030
Fax: (770) 879-4831
E-mail: mfleri@wmsgrpintl.com

Prime Contractor:
Jim Bannon
ESE
410 Amherst Street, Suite 100
Nashua, NH 03063
Telephone: (603) 889-3737
Fax: (603) 880-6111
E-mail: jpbannon@mactec.com

Technology:
Thermal Desorption
- Low temperature thermal desorption (LTTD) system owned by Williams Environmental, Inc
- System included a desorber unit that consisted of a direct-heated rotary kiln, feed belt, thermal desorber burner, and discharge screw conveyor; a baghouse unit; a thermal oxidizer unit; and a control unit
- Average system throughput - 27 tons/hr; residence time - 15 to 20 minutes; soil exit temperature - 650 to 750°F

Type/Quantity of Media Treated:
Soil
- 10,514 tons of soil
- Primarily coarse sand with small amounts of clay and silt
- Moisture content of <25%

Regulatory Requirements/Cleanup Goals:
The ROD specified the following soil cleanup levels: 1,2-dichloroethane - 0.1 mg/kg, 2-butanone - 0.3 mg/kg, 4-methyl-2-pentanone - 1.0 mg/kg, chloroform - 0.3 mg/kg, toluene - 1.5 mg/kg, trichloroethene - 0.2 mg/kg, total xylenes - 7.0 mg/kg

Results:
- All treated soil met the cleanup goals for the seven COCs on the first pass through the system
- Data on concentrations of specific COC contaminants was provided for samples collected between September and November 1997; these data showed that all seven COCs were at non-detectable levels in the treated soil
- Treated soil was backfilled on-site

Costs:
- The total project cost was $2,918,600, including $1,932,300 in costs for the thermal treatment application and $986,300 in other project costs such as excavation, compliance sampling, disposal of residuals and miscellaneous costs
- Treatment costs included $1,932,300, including $745,600 in capital costs and $1,186,700 in operating costs
- The calculated unit cost for treatment was $184 per ton based on treating 10,514 tons of soil

Thermal Desorption at the Sarney Farm Superfund Site, Amenia, New York

Description:
The Sarney Farm Superfund Site (Sarney Farm) is located in the town of Amenia in Dutchess County New York, approximately 90 miles north of New York City. The site encompasses 40 acres and includes a five-acre permitted sanitary landfill that operated from 1968 to 1969. During that time, non-permitted industrial wastes and barrels of waste solvents were disposed of in and around the landfill, as well as in trenches around the site. Site investigations indicated that soil and groundwater at the site were contaminated with organics, primarily VOCs. The ROD, signed in September 1990, specified removal of drums and excavation and on-site treatment of contaminated soil using low temperature thermal desorption for two areas. Removal of drums, which were disposed of off-site, was completed in March 1995.

The thermal treatment system used for this application was a low temperature thermal desorption (LTTD) system owned by Williams. A total of 10,514 tons of soil were treated from August through December 1997. All treated soil met the cleanup goals for seven COCs on the first pass through the system. The LTTD system reduced contaminant concentrations to non-detectable levels based on available data on individual contaminant concentrations. According to ESE, local permit constraints limited LTTD operation to daylight hours (about 10 to 11 hours per day), five days per week. Had the unit been allowed to operate 24 hours per day, seven days per week, the thermal treatment likely could be completed at a lower cost. According to Williams, this project was performed without the benefit of existing site utilities. Electricity was provided using an on-site generator; water was imported to the site on a daily basis using a tank truck; and soil was quenched using treated water from the excavation.

ThermoRetec's Segmented Gate System at Brookhaven National Laboratory, Area of Concern 16, Suffolk County, New York

Site Name:
Brookhaven National Laboratory, Area of Concern 16

Location:
Suffolk County, NY

Period of Operation:
May to June 2000

Cleanup Authority:
RCRA Corrective Measure

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:
Radionuclides
- Cesium 137 levels ranged from background to 348 pCi/g

Waste Source:
Spills of fission products

Site Contact:
James Brower
Brookhaven National Laboratory
Phone: (631) 344-7513

Vendor Contacts:
Joseph W. Kimbrell/James M. Brown
ThermoRetec
Phone: (505) 254-0955

Technical Contact:
Ray Patteson
Sandia National Laboratories
Phone: (505) 844-1904

Technology:
Segmented Gate System (SGS)
- SGS is a combination of conveyer systems, radiation detectors (primarily gamma radiation), and computer control
- Contaminated soil on conveyer 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 inches by width of 30.75 inches, and soil density of 1.29 g/cm^3
- Average daily processing time was 2.06 hours, with a total of 22.7 hours over 11 days

Type/Quantity of Media Treated:
Soil
- 625 yd^3 of soil were processed
- Moisture content relatively high; soil contained clumps of grass with root systems and grass stems

Regulatory Requirements/Cleanup Goals:
- Reduce the volume of contaminated soil that was above the specified criteria and that would require storage and disposal
- The sorting criterion was 23 pCi/g

Results:
- Overall volume reduction was measured as 16%, processing soil from three separate locations
- Average activity of above-criteria soil ranged from 26 - 321 pCi/g, and below-criteria soil ranged from 7.17 - 18.8 pCi/g

Costs:
- The vendor's cost was $373,509, including $52,410 for pre-deployment site characterization, $25,700 for other pre-deployment activities, $73,300 for mobilization, $147,459 for operations and delays, $49,000 for demobilization, $18,640 for post-excavation mower survey and $7,000 for the final report and documentation; BNL's costs were $321,000, including $136,662 for supporting the use of SGS
- Overall unit cost was $78/yd^3, based only on costs for processing activities

ThermoRetec's Segmented Gate System at Brookhaven National Laboratory, Area of Concern 16, Suffolk County, New York

Description:
Brookhaven National Laboratory (BNL), located in Suffolk County, New York, approximately 60 miles east of New York City, encompasses an area of 5,265 acres (approximately 8.21 square miles). The site was formerly occupied by the U.S. Army as Camp Upton during World Wars I and II, and was transferred to DOE in 1977. In 1980 and 1983, aerial radiation surveys were conducted at the BNL site and 23 areas of man-made radioactivity were identified. The source of the radioactive material was believed to be from spills of fission products removed from the hazardous waste management facility. The material at Area of Concern 16 was 137Cs radionuclide-contaminated landscape surface soil.

A Segmented Gate System (SGS) was used to reduce the volume of contaminated soil that required off-site disposal. SGS is a combination of conveyer systems, radiation detectors, and computer control, where contaminated soil on a conveyer 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 soil based on radioactivity criteria. At this site, the overall volume reduction was measured as 16%. This relatively low percentage was attributed to differences between requirements specified in the work plan and actual field conditions. The vendor's cost for the project was \$373,509, and BNL's cost was \$321,000. The overall unit cost was \$78/yd^3, based only on costs for processing activities

Thermo NUtech's Segmented Gate System at Idaho National Engineering and Environmental Laboratory, Auxiliary Reactor Area 23, Idaho Falls, Idaho

Site Name:
Idaho National Engineering and Environmental Laboratory (INEEL), Auxiliary Reactor Area (ARA) 23

Location:
Idaho Falls, ID

Period of Operation:
May to June 1999

Cleanup Authority:
CERCLA

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:
Radionuclides
- Cesium 137 levels greater than 45 pCi/g

Waste Source:
Accidental destruction of reactor

Site Contact:
Frank Webber
INEEL
(208) 526-8507

Vendor Contacts:
Joseph W. Kimbrell
ThermoRetec
(505) 254-0935 ext. 209

Technical Contact:
Ray Patteson
Sandia National Laboratories
(505) 844-1904

Technology:
Segmented Gate System (SGS)
- SGS is a combination of conveyer systems, radiation detectors (primarily gamma radiation), and computer control
- Contaminated soil on conveyer 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 inches by width of 30.75 inches, and soil density of 0.95 g/cm^3
- Actual run time was 4.12 hours for Area A, and 2.98 hours for Area C

Type/Quantity of Media Treated:
Soil
- 442 yd^3 of soil were processed, consisting of 124 yd^3 from Area A (Sediment Radionuclide Deposition), 219 yd^3 from Area C (Windblown Radionuclide Deposition), and 99 yd^3 of oversized material from Areas A and C
- Soils generally consisted of fine-grained eolian soil deposits, with some fluvial gravel and gravelly sands; sieve analysis not performed
- Moisture content relatively high; soil contained clumps of grass with root systems and grass stems

Regulatory Requirements/Cleanup Goals:
- Reduce the volume of contaminated soil that was above the specified criteria and that would require storage and disposal, from soil that was below the criteria
- The sorting criterion was 23 pCi/g

Results:
- Overall volume reduction was measured as 2.7% for Area A soils and 0% for Area C soils
- Several additional tests were performed to determine the cause of the relatively poor results, including a set point test, shine test, and direct haul tests

Costs:
- The vendor's cost was $205,800, including $17,000 for pre-deployment activities, $69,000 for mobilization, $77,000 for processing, $39,000 for demobilization, and $3,800 for final report; INEEL's costs were $365,000

Thermo NUtech's Segmented Gate System at Idaho National Engineering and Environmental Laboratory, Auxiliary Reactor Area 23, Idaho Falls, Idaho

Description:
INEEL, located 34 miles west of Idaho Falls, Idaho, encompasses an area of 890 square miles. The site was established in 1949 for building and testing a variety of nuclear facilities. INEEL supports the engineering and operations efforts of DOE and other federal agencies in the areas of nuclear safety research, reactor development, reactor operations and training, nuclear defense materials production, waste management technology, energy technology, and conservation programs. Auxiliary Reactor Area 23 is a 41.8 acre CERCLA site at INEEL containing windblown contamination. Most of the contamination came from the accidental destruction of the SL-1 reactor in 1961. The contaminant of concern at ARA 23 is 137Cs.

A SGS was used to reduce the volume of contaminated soil that required off-site disposal. SGS is a combination of conveyer systems, radiation detectors, and computer control, where contaminated soil on a conveyer 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 soil based on radioactivity criteria. At this site, the overall volume reduction was measured as less than 3%, and several tests were performed to determine the cause of the relatively poor results. The vendor's cost for the project was $205,800, and INEEL's cost was $365,000.

Solidification/Stabilization at the Massachusetts Military Reservation, Training Range and Impact Area, Cape Cod, Massachusetts

Site Name:
Massachusetts Military Reservation, Training Range and Impact Area

Location:
Cape Cod, MA

Period of Operation:
February 1998 through June 1998

Cleanup Authority:
CERCLA
- Administrative Order issued April 10, 1997

EPA Remedial Project Manager:
Mike Jasinski
U.S. EPA Region 1
1 Congress Street, Suite 1100
Boston, MA 02203-2211
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Fax: (617) 918-1291
E-mail: jasinski.mike@epa.gov

Purpose/Significance of Application:
Use of a proprietary stabilization technology to treat lead in both *in situ* and *ex situ* soils

Cleanup Type:
Full scale

Contaminants:
Heavy Metals
- Lead was the primary contaminant, with total lead concentrations in soil ranging as high as 12,200 mg/kg and TCLP leachable lead as high as 734 ug/L

Waste Source:
Training/firing ranges

Site Lead:
Ben Gregson, Assistant Project Officer
Army National Guard
Building 2816, Room 228
Camp Edwards, MA 02542
Telephone: (508) 968-5821
Fax: 508-968-5286

Technology Vendor:
Mike Lock or Chris Rice
Sevenson Environmental Services, Inc.
8270 Whitcomb Street
Merrillville, IN 46410
Telephone: (219) 756-4686
Fax: (219) 756-4687
E-mail: sevensonmw@aol.com

Technology:
Stabilization using MAECTITE®
- MAECTITE® is a proprietary technology that applies a liquid reagent to the soil to react with the lead and produce a geochemically stable synthetic mineral crystal; information was not provided on the type of chemicals in the liquid reagent
- Contaminated soil from sixteen small arms ranges was treated with MAECTITE® technology in both *ex situ* and *in situ* applications
- Berm soil was excavated and treated *ex situ* when a visual analysis showed the presence of recoverable bullet fragments
- Soil remaining in the berms that did not contain bullet fragments but still had a TCLP lead concentration of greater than 5.0 mg/L was treated *in situ*.

Type/Quantity of Media Treated:
Soil
- 23,168 cubic yards of soil; consisting of 17,788 cubic yards treated *ex situ* (27,952 tons), and 5,380 cubic yards treated *in situ*
- Soil was classified as sandy and included stones and other oversize materials captured on 6-inch, 2-inch, and number 4 screens, and had a pH ranging from 5.0 to 6.5

Regulatory Requirements/Cleanup Goals:
- The Administrative Order contained several requirements, including removing the maximum amount of lead munitions from the soil; recycling the removed lead munitions, as appropriate; and use of soil modifiers to minimize prospective bullet corrosion and lead migration
- A cleanup goal was established as TCLP leachable lead concentration in soil of <5.0 mg/L

Results:
- 17,788 cubic yards of soil were treated *ex situ* in 56 batches (each consisting of 500 tons of soil). All batches met the cleanup goal, with no retreatment required. In addition, 96% of the samples of *ex situ* treated soil had a TCLP leachable lead concentration of <0.5 mg/L (one order of magnitude lower than the cleanup goal).
- 5,380 cubic yards of soil were treated *in situ* with 29 samples analyzed after *in situ* treatment of soil. All locations met the cleanup goal, with no retreatment required. In addition, 97% of the samples of *in situ* treated soil had a TCLP leachable lead concentration of <0.5 mg/L (one order of magnitude lower than the cleanup goal).

Solidification/Stabilization at the Massachusetts Military Reservation, Training Range and Impact Area, Cape Cod, Massachusetts

Costs:

- The capital cost for MAECTITE® treatment of 23,168 cubic yards of contaminated soil was $3.5 million, with a calculated unit cost of $151 per cubic yard of soil treated
- The costs included *ex situ* and *in situ* treatment of berms, as well as mobilization, work plan preparation, negotiation support, meetings and briefings, reports, survey of berms, berm reconstruction, and decontamination
- *In situ* treatment was used at those berms and portions of berms which did not contain recoverable bullet fragments, thus limiting the amount of soil that was required to be excavated and treated on an *ex situ* basis.

Description:

The Massachusetts Military Reservation (MMR), founded by the Commonwealth of Massachusetts in 1935 as a National Guard training camp and federalized in 1940 to prepare for World War II, currently houses Otis Air National Guard Base, U.S. Coast Guard Air Station Cape Cod, and Army National Guard Camp Edwards. MMR covers 34 square miles of upper Cape Cod (approximately 22,000 acres), and borders the towns of Bourne, Falmouth, Mashpee and Sandwich, Massachusetts. MMR was placed on EPA's Superfund National Priority List in 1989, and has 78 pollution source areas currently identified and 10 major groundwater pollution plumes moving at approximately 1.5 to 2 feet per day. The reservation sits atop the recharge area for the sole source groundwater aquifer from which all of upper Cape Cod draws its drinking water. The Training Range and Impact Area includes 16 small arms firing ranges (training ranges). Berms constructed behind targets at the ranges to capture bullets and fragments of bullets behind targets became contaminated with lead.

MAECTITE®, a proprietary stabilization technology, was used on both an *ex situ* and an *in situ* basis to treat lead-contaminated soil in the berms at the 16 small arms ranges. A total of 23,168 cubic yards of soil were treated (17,788 cubic yards *ex situ* and 5,380 cubic yards *in situ*). All samples met the cleanup goal of <5.0 mg/L of TCLP leachable lead, and soil was not required to be retreated. The treatment vendor reported that the factors that affect cost and performance for the MAECTITE® technology include heavy metal constituents of concern, level of heavy metal contamination, reduction in concentrations of leachable metal, volume of material to be treated, whether *in situ* or *ex situ* methods are used, material sizing requirements, final disposition of treated material (i.e., on site or off site), reporting requirements, waste matrix complexities, site configuration, prevailing labor rates, and taxes.

Solidification/Stabilization at the New Bedford Harbor Superfund Site, New Bedford, Massachusetts

Site Name:
New Bedford Harbor Superfund Site

Location:
New Bedford, Massachusetts

Period of Operation:
November 30 to December 4, 1995

Cleanup Authority:
CERCLA
- ROD signed April 1990

Purpose/Significance of Application:
Bench-scale testing of solidification/stabilization to treat PCB-contaminated sediments

Cleanup Type:
Bench-scale

Contaminants:
PCBs
- Maximum concentrations in sediments of more than 200,000 mg/kg

Waste Source:
Discharge of polychlorinated biphenyl (PCB)-contaminated wastewater from electronics manufacturing

Site Contact:
Helen Douglas
Foster Wheeler Environmental Corporation
470 Atlantic Avenue
Boston, MA 02210
Telephone: (617) 457-8263
E-mail: helen_douglas@fwc.com

EPA Contact:
James M. Brown
U.S. EPA Region 1 (MC HBO)
1 Congress Street, Suite 1100
Boston, MA 02114
Telephone: (617) 918-1308
E-mail: brown.jim@epa.gov

Technology:
Solidification/Stabilization
- Bench-scale study of seven solidification/stabilization reagents from Foster Wheeler, MARCOR Environmental (MARCOR), and World Environmental (WORLD)
- Reagents included Foster Wheeler - Portland cement and absorbent clay; MARCOR - HWT-27 (a sintered calcium silicate material); and WORLD - LPC II (15% SiO_2 and 68% CaO, similar to Portland cement), Clarion SM-399 (complex of montmorillonite clay and quaternary ammonium compound), Zoneco-P1 (mixture of some 30 organic and amino acids and other organic compounds), and OT-P2 (liquid containing 40% active alkoxysilane emulsified in water)
- Reagents were mixed with sediments (proportions and length of mixing times varied); the mixtures were placed in molds and allowed to air cure for 30 days

Type/Quantity of Media Treated:
Sediment
- Fine sandy silt with some clay-sized particles present; some small shell fragments present
- Moisture content - 50% by weight

Regulatory Requirements/Cleanup Goals:
- Objectives of the bench-scale study included evaluating the ability of solidification/stabilization to reduce the leachability of PCBs, SVOCs, and heavy metals in Hot Spot sediments
- Toxicity Characteristic Leaching Procedure (TCLP) regulatory limits for SVOCs and metals
- For TCLP PCBs, no regulatory limit had been established; therefore, results were used for comparison purposes only
- Compressive strength of treated material

Results:
- TCLP PCBs - concentrations in all batches for the three vendors was found to be higher in the treated sediment than in the untreated sediment, by a factor of two to four times
- TCLP SVOCs - results were mixed, with concentrations generally higher in the treated sediment than in the untreated sediment; for example, TCLP concentrations for phenols increased in mixtures from all three vendors from 2 ug/L in the untreated sediment to as much as 4.7 ug/L in the treated material
- TCLP metals - concentrations in the untreated sediment used for these tests were below regulatory limits; in most cases, metals concentrations in the sediment were reduced by solidification/stabilization; however, increases in concentrations for several metals, including barium, copper, and zinc, were observed in some of the tests
- Compressive strength - the Foster Wheeler mixtures had the highest compressive strength, ranging from 195 to 270 psi; the MARCOR has the lowest compressive strength, ranging from 45 to 80 psi

Solidification/Stabilization at the New Bedford Harbor Superfund Site, New Bedford, Massachusetts

Costs:
No cost data were available for the treatability study; and no projections were developed for the full-scale costs for solidification/stabilization of Hot Spot sediments

Description:
The New Bedford Harbor Superfund Site is located along the northwestern shore of Buzzards Bay in New Bedford Massachusetts, approximately 55 miles south of Boston. From the 1940s to 1978, PCB-contaminated wastewater from electronics manufacturing operations was discharged onto the shoreline and into the harbor. Site investigations determined that sediments were contaminated with PCBs and heavy metals. The site was listed on the National Priorities List in September 1983. The ROD for a five acre area known as the "Hot Spot area" included dredging of PCB-contaminated sediments followed by incineration. However, due to opposition to incineration, EPA postponed the incineration component of the Hot Spot remedy to explore alternative treatment technologies. EPA evaluated four technologies as possible alternatives to incineration - solvent extraction/dechlorination, vitrification, thermal desorption/gas phase chemical reduction, and solidification/stabilization. This report covers the bench-scale testing of a solidification/stabilization process.

The bench-scale test was performed using seven reagents from three vendors - Foster Wheeler, MARCOR, and WORLD. The reagents were mixed with Hot Spot sediments (in varying proportions and mixed for varying times), placed in containers, and air cured for 30 days. Samples were analyzed for TCLP PCBs, TCLP SVOCs, and TCLP metals to evaluate the ability of solidification/stabilization to reduce the leachabiliy of contaminants from Hot Spot sediments. None of the solidification/stabilization mixtures tested during the bench-scale study was effective in stabilizing PCBs or SVOCs in the Hot Spot sediments. In many cases, the contaminant concentrations in the treated material were higher than in the untreated sediment. Specific reasons for the increase in concentrations were not identified, though it is possible that the process increased the mobility of PCBs and other organics in the aqueous phase. While the concentrations of metals in the untreated sediment were below the regulatory limits, solidification/stabilization generally reduced the TCLP metals concentrations in the treated material, and may be appropriate for treating metals in the Hot Spot sediments.

Solvent Extraction/Dechlorination at the New Bedford Harbor Superfund Site, New Bedford, Massachusetts

Site Name:
New Bedford Harbor Superfund Site

Location:
New Bedford, Massachusetts

Period of Operation:
June 1996

Cleanup Authority:
CERCLA
- ROD signed April 1990

Purpose/Significance of Application:
Demonstration of solvent extraction/dechlorination to treat PCB-contaminated sediments

Cleanup Type:
Field demonstration

Contaminants:
PCBs
- Maximum concentrations in sediments of more than 200,000 mg/kg

Waste Source:
Discharge of polychlorinated biphenyl (PCB)-contaminated wastewater from electronics manufacturing

EPA Contact:
James M. Brown
U.S. EPA Region 1 (MC HBO)
1 Congress Street, Suite 1100
Boston, MA 02114
Telephone: (617) 918-1308
E-mail: brown.jim@epa.gov

Technology Vendors:
William Heins
Ionics RCC
3006 Northrop Way, Suite 200
Bellvue, WA 98004
Telephone: (425) 828-2400

Gerry Getman
Commodore Advances Sciences, Inc.
2340 Menaul Boulevard NE, Suite 400
Albuquerque, NM 87107
Telephone: (505) 872-6805
Fax: (505) 872-6827
E-mail: ggetman@commodore.com

Technology:
Solvent extraction/dechlorination
- Basic Extractive Sludge Treatment (B.E.S.T.®) solvent extraction process followed by Solvated Electron Technology (SET®) dechlorination process
- B.E.S.T.® process included feed material preparation, extraction, solids drying, and solvent recovery; diisopropylamine (DIPA) used as the extraction solvent; PCB-concentrated oil sent to SET® process
- SET® process included a mobile SET® unit with a one gallon per day processing capacity; concentrated oil reacted with liquid anhydrous ammonia followed by metallic sodium generating the solvated electron solution to reduce the PCBs
- Pilot testing included optimization testing to identify the optimum process parameters required to maximize extraction of PCBs from the sediment, and verification testing to collect data from the process operating under optimal conditions

Type/Quantity of Media Treated:
Sediment
- Fine sandy silt with some clay-sized particles present; some small shell fragments present
- Moisture content - 50% by weight

Regulatory Requirements/Cleanup Goals:
- Target goals for demonstration were 50 mg/kg for PCBs and the Toxicity Characteristic Leaching Procedure (TCLP) criteria for metals

Results:
- The B.E.S.T.® process reduced concentrations of PCBs in sediments from as high as 2,515 mg/kg to below the target treatment goal of 50 mg/kg in as few as five extraction cycles, and PCB concentrations below 10 mg/kg were achieved after seven extraction cycles; TCLP metals in the treated sediment were below regulatory levels
- The SET® process reduced concentrations of PCBs in the concentrated oil from the B.E.S.T.® process from 49,000 mg/kg to levels ranging from not detected to 38 mg/kg, below the target treatment goal of 50 mg/kg

Solvent Extraction/Dechlorination at the New Bedford Harbor Superfund Site, New Bedford, Massachusetts

Costs:

- The projected full-scale cost for treatment of PCB-contaminated sediment using the combined B.E.S.T.® and SET® processes were $12,971,000, including $9,000,000 in capital costs and $3,971,000 in O&M costs
- Projected full-scale costs were based on treating 18,000 tons of sediment, for a unit cost of $721 per ton

Description:

The New Bedford Harbor Superfund Site is located along the northwestern shore of Buzzards Bay in New Bedford Massachusetts, approximately 55 miles south of Boston. From the 1940s to 1978, PCB-contaminated wastewater from electronics manufacturing operations was discharged onto the shoreline and into the harbor. Site investigations determined that sediments were contaminated with PCBs and heavy metals. The site was listed on the National Priorities List in September 1983. The ROD for a five acre area known as the "Hot Spot area" included dredging of PCB-contaminated sediments followed by incineration. However, due to opposition to incineration, EPA postponed the incineration component of the Hot Spot remedy to explore alternative treatment technologies. EPA evaluated four technologies as possible alternatives to incineration - solvent extraction/dechlorination, vitrification, thermal desorption/gas phase chemical reduction, and solidification/stabilization. This report covers the pilot-scale test of a solvent extraction/dechlorination process.

The pilot test was performed using the patented Ionics RCC B.E.S.T.® solvent extraction process to remove contaminants from the sediments, followed by the Commodore SET® process to treat the high concentration PCB oil from the B.E.S.T.® process. During the pilot test, the B.E.S.T.® process reduced concentrations of PCBs from as high as 2,515 mg/kg to 10 mg/kg; TCLP metals in the treated sediment were below regulatory levels. The SET® process reduced concentrations of PCBs in the concentrated oil from 49,000 mg/kg to below the levels ranging from not detected to 38 mg/kg. During the pilot test, problems were encountered with the feed mechanism for the SET® process, requiring modifications to the design and operation of the unit. These included modifying the feed mechanism design to handle semi-solid, waxy material rather than liquid and using excess sodium to address problems with untreated material contaminating treated material.

Vitrification at the New Bedford Harbor Superfund Site, New Bedford, Massachusetts

Site Name:
New Bedford Harbor Superfund Site

Location:
New Bedford, Massachusetts

Period of Operation:
July - August 1996

Cleanup Authority:
CERCLA
- ROD signed April 1990

Purpose/Significance of Application:
Demonstration of vitrification to treat PCB-contaminated sediments

Cleanup Type:
Field demonstration

Contaminants:
PCBs
- Maximum concentrations in sediments of more than 200,000 mg/kg

Waste Source:
Discharge of polychlorinated biphenyl (PCB)-contaminated wastewater from electronics manufacturing

EPA Contact:
James M. Brown
U.S. EPA Region 1 (MC HBO)
1 Congress Street, Suite 1100
Boston, MA 02114
Telephone: (617) 918-1308
E-mail: brown.jim@epa.gov

Technology Vendor:
James Hansen
Geosafe Corporation
2952 George Washington Way
Richland, WA 99352
Telephone: (509) 375-0170
Fax: (509) 375-7721

Technology:
Vitrification:
- Geosafe's pilot-scale vitrification system with a treatment capacity of 2,000 pounds per batch
- System included two cylindrical carbon steel test containers (60 inches high and 50 inches in diameter) set inside carbon steel containment boxes; electrodes were placed inside each container, along with thermocouples to monitor the temperature of the melt
- Off-gas equipment included desiccant and carbon filters, caustic scrubber, vapor-phase carbon filter, and thermal oxidizer
- Batch No. 1 - power applied for 34 hours with an average melt rate of 0.93 in/hr with a total of 785 kWhr of energy consumed; achieved a melt depth of 31.5 inches based on a reading of 1000°C centerline temperature; during this batch, significant steam was generated causing particulates and organics to be released in the off-gas; these problems were attributed to the high moisture content and the fine-grained nature of the sediment
- Batch No. 2 - power applied for 22 hours with an average melt rate of 0.9 in/hr with a total of 522 kWhr of energy consumed; achieved a melt depth of 33 inches based on a reading of 1000°C centerline temperature; to alleviate the problems in Batch No. 1, standing water was decanted from the sediments in the test container prior to the test

Type/Quantity of Media Treated:
Sediment
- Fine sandy silt with some clay-sized particles present; some small shell fragments present
- Moisture content - >50% by weight

Regulatory Requirements/Cleanup Goals:
- Target goals for demonstration were 50 mg/kg for PCBs and the Toxicity Characteristic Leaching Procedure (TCLP) criteria for metals

Results:
- During Batch No. 1, operational difficulties were encountered as a result of the high moisture content and fine-grained nature of the sediment. Geosafe considered this batch to be an optimization test and Batch No. 2 to be the verification test. Therefore, data from the Batch No. 1 test was not included in the performance analysis
- Data from Batch No. 2 showed that PCB concentrations in the melt were reduced from as high as 2,085 mg/kg to below detectable levels in the treated sediment; the destruction removal efficiency for the process was 99.9905% for PCBs; TCLP metals concentrations in the melt were below the regulatory criteria

Vitrification at the New Bedford Harbor Superfund Site, New Bedford, Massachusetts

Costs:

- The projected full-scale cost for vitrification of sediments was $20,687,000
- Projected full-scale costs were based on treating 18,000 tons sediment, for a unit cost of $1,149 per ton
- According to the vendor, this projected full-scale cost was based on treating sediments with a high moisture content; unit costs for vitrification of dry sludge are generally lower (about $400 per ton)

Description:

The New Bedford Harbor Superfund Site is located along the northwestern shore of Buzzards Bay in New Bedford Massachusetts, approximately 55 miles south of Boston. From the 1940s to 1978, PCB-contaminated wastewater from electronics manufacturing operations was discharged onto the shoreline and into the harbor. Site investigations determined that sediments were contaminated with PCBs and heavy metals. The site was listed on the National Priorities List in September 1983. The ROD for a five acre area known as the “Hot Spot area” included dredging of PCB-contaminated sediments followed by incineration. However, due to opposition to incineration, EPA postponed the incineration component of the Hot Spot remedy to explore alternative treatment technologies. EPA evaluated four technologies as possible alternatives to incineration - solvent extraction/dechlorination, vitrification, thermal desorption/gas phase chemical reduction, and solidification/stabilization. This report covers the pilot-scale test of a vitrification process.

The pilot test was performed using Geosafe’s vitrification system with a treatment capacity of 2,000 pounds per batch. Pilot tests were completed for two batches: Batch No. 1, where power was applied for 34 hours, achieving a melt depth of 31.5 inches; and Batch No. 2, where power was applied for 22 hours, achieving a melt depth of 33 inches. During Batch No. 1, operational difficulties were encountered as a result of the high moisture content and fine-grained nature of the sediment. As such, only data from Batch No. 2 were used for the performance assessment. To alleviate the operational problems from Batch No. 1, water was decanted from the sediments prior to testing of Batch No. 2. The results from Batch No. 2 showed that the vitrification process reduced PCB concentrations from 2,085 mg/kg to below detectable levels in the treated sediment, with a PCB destruction removal efficiency of 99.9905%. TCLP metals concentrations in the melt were below the regulatory criteria. According to Geosafe, full-scale *in situ* vitrification technology is not the technology of choice for treating soils/sediments with a high moisture content (i.e., fluid media). The first test was performed on sediments that contained standing water. While the water was decanted from the sediment for the second test, the moisture content of the sediment tested was above 50 percent. Geosafe indicated that dewatering the sediment to a moisture content of 10% prior to treatment would address the problem.

Bioremediation at the Stauffer Management Company Superfund Site, Tampa, Florida

Site Name:
Stauffer Management Company Superfund Site, Tampa, Florida

Location:
Tampa, Florida

Period of Operation:
June 1997 - September 1998

Cleanup Authority:
CERCLA - ROD issued December 1995

Purpose/Significance of Application:
Demonstration of composting technology for treatment of soil contaminated with chlorinated pesticides

Cleanup Type:
Field demonstration

Contaminants:
Organochlorine Pesticides - Typical pesticide concentrations in the soil were chlordane - 47.5 mg/kg; DDD - 162.5 mg/kg; DDE - 11.3 mg/kg; DDT - 88.4 mg/kg; dieldrin - 3.1 mg/kg; molinate - 10.2 mg/kg; and toxaphene - 469 mg/kg

Waste Source:
Pesticide manufacturing and distribution

PRP Project Lead
Frank Peter
SMC
405 Bartram Lane
West Hockessin, DE 19707
(302) 239-6781
jfpeter@aol.com

EPA Remedial Project Manager
Brad Jackson
U.S. EPA Region 4
61 Forsyth Street, S.W.
Atlanta, GA 30303-8960
(404) 562-8925
jackson.brad@epa.gov

Technology:
Bioremediation (composting)
- This technology is registered by SMC as Xenorem^{TM}
- For the field demonstration, excavated soil was passed through a 2" screen and then mixed and placed in a pile for treatment
- Amendments (cow manure and straw) were added to the pile five times over a period of 48 weeks
- Anaerobic and aerobic operating cycles were varied to maximize contaminant destruction rates

Type/Quantity of Media Treated:
Soil
- 905 yd^3 for initial pile; total volume of 1,193 yd^3 with amendments

Regulatory Requirements/Cleanup Goals:
- The ROD identified cleanup levels for seven constituents in surface (0-2 ft bgs) soil: chlordane - 2.3 mg/kg; DDD - 12.6 mg/kg; DDE - 8.91 mg/kg; DDT - 8.91 mg/kg; dieldrin - 0.19 mg/kg; molinate - 0.74 mg/kg; and toxaphene - 2.75 mg/kg
- Objectives of the field demonstration were to reach ROD levels or achieve 90% reduction in concentrations; evaluate effects of pile geometry; and evaluate equipment

Results:
- Concentrations in the compost pile were measured for the seven constituents with cleanup levels, 14 other chlorinated pesticides, and 11 thiocarbamate and organo-phosphate compounds
- Concentrations were measured at the start of the field demonstration (T0) and at the end (T64) of a 64 week period
- The cleanup levels were achieved for 4 of 7 constituents (DDE, DDT, dieldrin, and molinate)
- DDD and toxaphene concentrations were reduced by more than 90%; chlordane concentrations were reduced by nearly 90%

Costs:
- No data are available about the cost for the field demonstration
- SMC provided typical costs for use of this technology for treating chlorinated pesticides; projected costs for treatment are \$132/yd^3, with total project costs of \$192/yd^3

Bioremediation at the Stauffer Management Company Superfund Site, Tampa, Florida

Description:
The Stauffer Management Company (SMC) Superfund site is an inactive pesticide manufacturing/distribution facility in Tampa, Florida. From 1951 to 1986, the site was used to formulate organochlorine and organophosphate pesticides. From 1953 to 1973, waste materials from the facility were disposed of on site, leading to pesticide contamination in soil, surface water, sediment, and groundwater.

A ROD, signed in December 1995, specified bioremediation for treatment of pesticide-contaminated surface soils and sediments at the site. From June 1997 to September 1998, a field demonstration of SMC's Xenorem^{TM} composting process was conducted in an enclosed warehouse at the site, using soil taken from "hot spots" at the site. Amendments consisted of cow manure and straw, and the pile was alternated between anaerobic and aerobic conditions.

The ROD identified cleanup levels for seven constituents in surface soil, and concentrations of these and other constituents were measured at the start and end of the field demonstration, over a 64 week period. The cleanup levels were achieved for DDE, DDT, dieldrin, and molinate, but not for chlordane, DDD, or toxaphene. Concentrations of DDD and toxaphene were reduced by more than 90% and chlordane by nearly 90%. Although no data are available about the cost for the field demonstration, SMC indicated that typical costs for use of this technology for treating chlorinated pesticides are \$132/yd^3.

DRINKING WATER TREATMENT FOR MTBE ABSTRACTS

Ex Situ Advanced Oxidation Processes, Granular Activated Carbon, and Synthetic Resin Adsorption Treatment at the Charnock Wellfield, California

Site Name: Charnock Wellfield	**Location:** Santa Monica, California
Period of Operation: July 1998 - April 1999	**Cleanup Authority:** State of California
Purpose/Significance of Application: Pilot-scale testing of Advanced Oxidation Processes (AOP) to treat MTBE and TBA in drinking water	**Cleanup Type:** Pilot scale
Contaminants: MTBE, TBA	**Waste Source:** Leaks from gasoline pipelines and underground storage tanks

Site Contact:
Gil Borboa
City of Santa Monica, Utilities Division
1212 5th Street, 3rd Floor
Santa Monica, CA 90401
Telephone: (310) 458-8230
Fax: (310) 393-6697
E-mail: Gil-borboa@ci.santa-monica.ca.us

Consultant:
Craig E. Dial, P.E.
Kennedy/Jenks Consultants
2151 Michelson Drive, Suite 100
Irvine, CA 92612-1311
Telephone: (949) 261-1577
Fax: (949) 261-2134
E-mail: CraigDial@KennedyJenks.com

EPA Contact:
Steve Linder
U.S. EPA Region 9
75 Hawthorne Street, WST-8
San Francisco, CA 94105
Telephone: (415) 744-2036
Fax: (415) 744-1026
E-mail: linder.steven@epa.gov

Technology:
AOP - UV/Peroxide and UV/Peroxide followed by GAC

- UV/Peroxide - system included a Calgon Rayox™ tower configured for upflow operation equipped with three UV lamps that operatd at 23.5 kilowatts (kW). Peroxide dosing resulted in peroxide concentrations of 20 to 60 mg/L. Water retention times for the tower were 2 to 4 minutes for flow rates of 150 to 300 gpm, respectively. To prevent scaling, groundwater was pre-treated by filtration.
- UV/Peroxide followed by GAC - effluent from the Rayox™ tower was treated using three 2,000 pound vessels containing Calgon Carbon's Centaur carbon to remove residual peroxide followed by three 2,000 pound vessels containing Calgon Carbon's Fitrasorb 300 carbon to remove residual MTBE and by-products.
- UV/Peroxide followed by GAC - Operated in Parallel - three types of GAC units operated in parallel - Calgon Carbon's Centaur carbon, Calgon Carbon's Fitrasorb 300, and coconut shells. Each 2,000 pound unit contained an upflow column (12 inches in diameter and 8.5 feet in length) and a downflow column (8 inches in diameter and 8.5 feet in length). The flow rate was 2 gpm through each of the units.

Type/Quantity of Media Treated:
Drinking Water

Regulatory Requirements/Cleanup Goals:
The target MTBE treatment goal for the Charnock Treatment Plant is 13 ug/L; risk-based drinking water action level established by the California Department of Health Services for chemicals for which primary MCLs have not been adopted.

Ex Situ Advanced Oxidation Processes, Granular Activated Carbon, and Synthetic Resin Adsorption Treatment at the Charnock Wellfield, California

Results:

- At the time of this report, only limited data were available on MTBE concentrations in the effluent from the UV/peroxide process Rayox™ tower.
- According to the PRP's consultant, one reported value for MTBE in the Rayox tower effluent was below the detection limit of 3 ug/L, based on an influent MTBE concentration of 80 ug/L. In addition, tests run with MTBE-spiked water at 1,000 ug/L and a flow rate of 210 gpm reduced MTBE effluent concentrations to 2 to 4 ug/L.

Costs:

- Projected capital equipment cost for a proposed full-scale UV/peroxide system is approximately \$4 to \$5 million, including four 1,200-gpm Rayox™ towers equipped with 24 30-kW UV lamps. This cost does not include installation, purchasing suitable property (approximately 40,000 square feet), or installing a pipeline between Arcadia and Charnock (estimated at \$1 million per mile).
- Operating costs of the full-scale system are estimated to be \$1.50 to \$1.75 per 1,000 gallons of treated water.

Description:

The Charnock Sub-basin, located in the Mar Vista section of West Los Angeles, includes the Upper Silverado aquifer containing two municipal wellfields. In March 1996, MTBE was detected in drinking water at the Charnock Wellfield. MTBE concentrations in groundwater ranged from 130 micrograms per liter (ug/L) to 610 ug/L. In August 1998, tertiary butyl alcohol (TBA) was discovered in the shallow groundwater near the Charnock Wellfield. Two intrastate gasoline pipelines and 24 underground storage tank sites have been identified as possible sources of the groundwater contamination. The potentially responsible party (PRP) group's engineering consultant, Kennedy/Jenks (KJ), began pilot studies to evaluate treatment technologies for the removal of MTBE and TBA.

Pilot testing was conducted on UV/peroxide, UV/peroxide followed by GAC units operated in series, and UV/peroxide followed by three sets of GAC units operated in parallel. Limited data available at the time of this report showed MTBE concentrations below the detection limit of 3 ug/L in the effluent from the UV/peroxide process Rayox™ tower, and MTBE effluent concentrations reduced to 2 to 4 ug/L during tests run with MTBE-spiked water at 1,000 ug/L A 3,500 gpm treatment system is proposed for construction if the pilot studies find that the UV/peroxide system is technically feasible and cost effective. The projected capital costs for a full-scale system are \$4 to \$5 million, with operation costs of \$1.50 to \$1.75 per 1,000 gallons of water treated.

Ex Situ Air Stripping at LaCrosse, Kansas

Site Name:
LaCrosse

Location:
LaCrosse, Kansas

Period of Operation:
1997 to present (data available through September 1999)

Cleanup Authority:
State of Kansas

Purpose/Significance of Application:
Use of air stripping to treat MTBE in drinking water

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX, TPH
- MTBE concentrations as high as 1,050 ug/L in public water supply wells

Waste Source:
Leaks from underground storage tanks

State Contacts:
Bill Reetz/Greg Hatten
Kansas Department of Health and Environment
Building 740, Forbes Field
Topeka, KS 66620
Telephone: (785) 296-3103/5931
Fax: (785) 296-6190
E-mail:
breetz@kdhe.state.ks.us/ghattan@kdhe.state.ks.us

Vendor:
Joe Brown
Industrial Plastics Systems (formerly Process Equipment and Engineering)
4225 Dranefield Road
Lakeland, FL 33811
Telephone: (863) 646-2010
Fax: (863) 644-1534
E-mail: www.ips-frp.com

Site Contractor:
Craig Hofmeister
Handex of Colorado
400 Corporate Circle, Suite T
Golden, CO 80401
Telephone: (303) 271-1050 x115
Fax: (303) 271-0446
E-mail:
chofmeister@handexmail.com

Technology:
Air stripping
Temporary air stripping system was operated from April to September 1997 as emergency response measure:
- Five-tray stripper designed to treat water from the clear well; system flow rate was 250 gallons per minute (gpm).

Permanent air stripping system was installed in September 1997 and is still in operation:
  - Two packed air stripping towers, each 33 feet tall by 6 feet in diameter, operated in series
  - Packed with 2-inch Jaeger Tri-pack filled to 21 feet; design air to water ratio of 150:1; design flow rate is 480 gpm for MTBE influent concentrations of up to 1,000 ug/L
  - First tower is designed to remove MTBE to levels below 20 ug/L; the second tower is used to polish the water.
  - Each tower is equipped with a blower designed to circulate 10,000 cubic feet per minute (cfm) of air
  - Influent to first tower is softened with lime and settled; effluent from the second tower is pumped through a sand and anthracite filter prior to entering the distribution system

Type/Quantity of Media Treated:
Drinking Water

Regulatory Requirements/Cleanup Goals:
The treatment goal for MTBE is 10 ug/L in the effluent from the air stripping system

Ex Situ Air Stripping at LaCrosse, Kansas

Results:
Temporary Stripper - During five months of operation, MTBE influent levels of 200-600 ug/L were reduced to concentrations ranging from 17-375 ug/L, an average reduction of 40 percent.
Permanent System - From September 1997 through September 1999, MTBE effluent concentrations were consistently below the treatment goal of 10 ug/L (about 93% of the time), and were below the detection limit of 0.2 ug/L almost 30 percent of the time. The average percent reduction in MTBE concentrations was 83% after the first stripper tower and 95% after the second stripper tower.

Costs:
The total capital cost for the packed tower system was $185,000. The operation and maintenance costs are $30,000 per year. The treatment system is operated by city personnel. No costs were provided for the temporary air stripping system.

Description:
The city of LaCrosse operates a drinking water treatment plant that provides water for the city's residents. The plant treats approximately 300 gallons per minute (gpm) in the winter and 450 gpm in the summer. In April 1997, two LaCrosse PWS wells were found to be contaminated with MTBE, BTEX, and other petroleum hydrocarbons. The source of the contamination was determined to be leaking underground storage tanks (UST) at three gasoline service stations. found in the wells. In April 1997, as an emergency response measure, a temporary air stripping system for treating MTBE was installed to allow the wells to continue to be used as the city's water supply source. The permanent air stripping system was installed in September 1997 and is still in operation. The system includes two packed air stripping towers, each 33 feet tall by 6 feet in diameter, operated in series.

During the first two years of operation, the dual packed tower air stripping system at the LaCrosse treatment plant has consistently reduced MTBE concentrations in the source wells to below the cleanup goal of 10 ug/L. There have been no exceedances of the cleanup goal during the last 12 months of operation. According to the State, the stripping system appears to be less efficient during extremely cold weather. Ambient air is pulled from outside the building into the air stripper blowers with no preliminary heating process. The total capital cost for the packed tower system was $185,000, with annual operation and maintenance costs of $30,000. No significant operation or maintenance problems have been reported and there have been no problems with fouling or scaling to date.

Ex Situ Air Stripping and GAC Treatment of Drinking Water at the Rockaway Township Site, Rockaway, New Jersey

Site Name:
Rockaway Township

Location:
Rockaway Township, New Jersey

Period of Operation:
1980 to present

Cleanup Authority:
State
- NJDEP Administrative Consent Order

Purpose/Significance of Application:
Use of air stripping and GAC to treat MTBE in drinking water

Cleanup Type:
Full scale

Contaminants:
MTBE, diisopropyl ether (DIPE), TCE, other VOCs, TBA
- Concentrations of MTBE in the supply wells ranged from 25 to 40 ug/L; DIPE concentrations ranged from 70 to 100 ug/L

Waste Source:
Leaks from underground storage tanks from a gasoline service station

State Contact:
Vincent Monaco
NJ Department of Environmental Protection (NJDEP)
Bureau of Safe Drinking Water
P.O. Box 426
401 East State Street, 3rd Floor
Trenton, NJ 08625-0426
Telephone: (609) 292-5550
Fax: (609) 292-1654

Site Contact:
Robert Sheard
Rockaway Township
65 Mount Hope Road
Rockaway, NJ 07866
Telephone: (973) 983-2876
Fax: (973) 625-7764
E-mail: rsds321@aol.com

Vendor:
Fenton Purcell
Lee T. Purcell Associates
60 Hamilton Street
Paterson, NJ 07505
Telephone: (973) 278-5700
Fax: (973) 278-8410
E-mail: purclfen@galaxy.net

Technology:
Air stripping followed by granular activated carbon (GAC)
- GAC system - two downflow pressure contactors (20 feet high and 10 feet in diameter and containing 20,000 pounds of Calgon F-300 carbon) operated in parallel; rated capacity of 1,000 gpm
- Air Stripping (original) - aluminum, countercurrent packed column (35 feet high and 9 feet in diameter, packed with 1,640 cubic feet of 3-inch polyethylene telerettes); design capacity of 1,400 gpm; design air flow rate was 37,500 cubic feet per minute (cfm) with an air-to-water ratio of 200:1
- Air Stripping (1993) - the corroded aluminum column was replaced with a same size fiberglass air stripper. Because MTBE was no longer observed in the supply wells, the fiberglass air stripper was redesigned to focus on the removal of TCE and DIPE, rather than MTBE. The new design uses a 30 hp blower and 20,000 cfm of air flow

Type/Quantity of Media Treated:
Drinking Water

Regulatory Requirements/Cleanup Goals:
No specific treatment goals for MTBE were provided.

Results:
- GAC-only system (October 1980 to February 1982) - initially, effluent concentrations of contaminants were reduced to below detectable limits; GAC break through in January 1981 resulted in increases in MTBE and DIPE concentrations; carbon was replaced in March 1981; subsequent carbon replacement was required once every four to six weeks, until aeration was added as a pretreatment step
- Air Stripping and GAC system (February 1982 to ongoing) - following addition of the air stripper, MTBE and DIPE concentrations were reduced, falling to 1 ug/L by December 1992. In 1993, MTBE was no longer detected, and the system was reconfigured (described above) to focus on treatment of TCE and DIPE. As of July 2000, no MTBE or TBA found in the supply wells; system continuing to operate to treat TCE and other VOCs

Ex Situ Air Stripping and GAC Treatment of Drinking Water at the Rockaway Township Site, Rockaway, New Jersey

Costs:
Air Stripping - capital cost - $375,000, including the column, packing media, blowers, piping, controls, site work, and booster pumps; annual operating cost (primarily cost for power) - $100,000, based on a cost for electricity of $0.09/kW-hr
GAC - capital cost - $200,000, including the contactors, GAC, piping, site work, and the building; annual operating cost (primarily carbon replacement) - $200,000 ($0.52/1,000 gallons of water treated)

Description:
The Rockaway Township, located in northern New Jersey, owns and operates a water supply system that provides drinking water to about half of the township's population. The system supplies groundwater from two wells (wells 6 and 7). The supply wells were found to be contaminated with MTBE and DIPE at levels ranging from 25 to 40 ug/L, and 70 to 100 ug/L, respectively. TCE and other VOCs were also found in the supply wells. The source of the contamination was identified as a gasoline service station (Shell Oil). To treat the drinking water from the supply wells, a GAC system was initially installed in 1980. However, during operation, breakthrough of MTBE and DIPE occurred relatively quickly and air stripping was added in Ferbruary 1982 to help extend the life of the carbon.

By 1993, MTBE was no longer detected in the supply wells. However, in 1997, a Shell Oil gasoline service station developed a leak, with MTBE entering the Rockaway Township drinking water supply wells. MTBE levels in the supply wells were found at concentrations ranging from 1 - 8 ug/L. Shell Oil installed an off site treatment plant which contained the MTBE to within minimal levels. In addition, TBA was also detected in the supply wells. According to the Rockaway Township, as of July 2000, no MTBE or TBA were being found in the supply wells. The air stripper/GAC treatment system is continuing to remove TCE and other VOCs (1,1-DCE, 1,1-DCA) from the supply wells.

PUMP AND TREAT ABSTRACTS

Pump and Treat for at OU1 and OU2 of the Marine Corps Air Station, Camp Lejeune, North Carolina

Site Name: Marine Corps Air Station - OU1 and OU2	**Location:** Camp Lejeune, North Carolina
Period of Operation: OU1 - January 1995 to present OU2 - January 1996 to present	**Cleanup Authority:** CERCLA • ROD for OU1 signed September 1994; OU2 signed September 1993
Purpose/Significance of Application: Use of pump and treat system to remediate groundwater contaminated with organics and metals	**Cleanup Type:** Full scale
Contaminants: OU1 - PCBs, pesticides, metals, chlorinated solvents, and BTEX OU2 - VOCs	**Waste Source:** OU1 - disposal of transformer oil, wastes from pesticide mixing operations and industrial operations; OU2 - disposal of PCBs, cleaning solvents, waste oils, used batteries, spent ammunition and other wastes
Contact: Naval Facilities Engineering Command 1100 23rd Avenue Port Hueneme, CA 93043	**Technology:** Pump and Treat OU1 system • Three extraction wells; six-inch diameter stainless steel casing and wire-wrap screen; 35 feet deep • 18 shallow monitoring wells (screened 5-25 ft deep), two intermediate wells (screened 55-75 ft deep), and two deep wells (screened 130 to 150 feet deep) • Aboveground treatment - oil/water separation, flocculation/filtration, air stripping, and granular activated carbon adsorption; water discharged to a sanitary sewer; design flow rate - 80 gpm OU 2 system • Six shallow extraction wells, each 35 ft deep and four deep extraction wells ranging in depth from 101-154 ft; six-inch stainless steel casing with 10-slot wire wrap screen for shallow wells and 20-slot wire wrap screen for deep wells; shallow well pumping rate ranges from 4-8 gpm per well; deep well pumping rate ranges from 30 to 150 gpm per well • Aboveground treatment - air stripping , filtration, and granular activated carbon adsorption; iron removal pretreatment for shallow well water; discharge to a creek
	Type/Quantity of Media Treated: Groundwater • OU1 - water table is 4 to 14 feet bgs; surficial aquifer extends 50 to 100 feet bgs with a transmissivity of 75 ft^2/day and is unconfined; deeper water-bearing deposits comprise the Castle Hayne aquifer with a transmissivity of 4,300 to 7,300 ft^2/day • OU2 - water table is 2 to 15 ft bgs; surficial aquifer extends to 50 feet bgs with a transmissivity of 75 ft^2/day; hydraulic characteristics of Castle Hayne aquifer underlying OU2 were not characterized

Pump and Treat for at OU1 and OU2 of the Marine Corps Air Station, Camp Lejeune, North Carolina

Regulatory Requirements/Cleanup Goals:

OU1

- Groundwater cleanup goals - benzene (1 ug/L), 1,2-dichloroethene (70 ug/L), ethylbenzene (29 ug/L), heptachlor expoxide (0.2 ug/L), tetrachloroethene (0.7 ug/L), toluene (1,000 ug/L), trichloroethene (2.8 ug/L), vinyl chloride (0.015 ug/L), xylenes (400 ug/L), arsenic (50 ug/L), barium (1,000 ug/L), beryllium (4 ug/L), chromium (50 ug/L), manganese (50 ug/L), vanadium (110 ug/L); hydraulic control
- Effluent must meet federal and North Carolina standards prior to discharge to the sanitary sewer

OU2

- Groundwater cleanup goals - 1,2-dichloroethene (0.38 ug/L), trans-1,2-dichloroethene (70 ug/L), ethlybenzene (29 ug/L), tetrachloroethene (0.7 ug/L), trichloroethene (2.8 ug/L), vinyl chloride (0.015 ug/L), arsenic (50 ug/L), barium (1,000 ug/L), beryllium (4 ug/L), lead (15 ug/L), chromium (50 ug/L), manganese (50 ug/L), mercury (1.1 ug/L), vanadium (110 ug/L); hydraulic control
- Effluent must meet North Carolina standards prior to discharge to a creek

Results:

OU 1

- After 2.5 years of operation, cumulative mass removed - 12 pounds of total VOCs; six pounds removed during first three months of operation and six pounds removed during past 27 months - 0.22 pounds/month; monthly total VOC influent concentrations relatively low (<400 ug/L)
- Effluent from treatment plant has consistently met discharge limits; however, low hydraulic conductivity of the shallow aquifer has resulted in influent treatment plant flow rates of <9% of design capacity

OU2

- From January 1997 to March 1999, 41,000 pounds of total VOCs removed; influent VOC concentrations for deep zone show slight increase, indicating possible presence of DNAPL; influent VOC concentrations for shallow zone relatively stable
- Effluent from treatment plant has consistently met discharge limits with the exception of PCE on three occasions and mercury on two occasions

Costs:

OU 1

- Average cost per pound of contaminant removed - $28,277
- Monthly O&M costs for the treatment plant were $12,300 during 1999; detailed O&M costs and system capital cost data were not available

OU2

- Average cost per pound of contaminant removed - $49
- Capital costs for the treatment plant were $4,660,000 and monthly O&M costs were $36,492 during 1999

Description:

The Marine Corps Air Station is co-located with the Marine Corps Base in Camp Lejeune, North Carolina. A ROD was signed for two operable units at the installation - OU1 consisting of three sites where pesticides, PCBs, waste oils, and other industrial waste had been disposed, and OU2 consisting of three sites where solvents, oils, spent ammunition, and other wastes has been disposed. Soil and groundwater at OU1 and OU2 were determined to be contaminated with organics and metals. The RODs specified pump and treat to remediate groundwater at these OUs.

An effectiveness evaluation for the pump and treat systems at this site was performed as part of a study by the Remedial Action Operation/Long Term Monitoring working group led by the Naval Facilities Engineering Service Center. The OU1 system has removed only 12 pounds of VOCs in 2.5 years and the treatment system is operating at less than 9% of design capacity. The OU2 system has removed more than 40,000 pounds of VOCs in a little more than two years of operation. The report includes detailed recommendations for each system.

Pump and Treat for the Campbell Street Fuel Farm at the Marine Corps Air Station, Camp Lejeune, North Carolina

Site Name:
Marine Corps Air Station - Campbell Street Fuel Farm (CSFF), Building AS-143, and Building AS-4151 sites

Location:
Camp Lejeune, North Carolina

Period of Operation:
1996 to present

Cleanup Authority:
State of North Carolina UST program

Purpose/Significance of Application:
Use of pump and treat system to remediate BTEX and SVOC groundwater contamination at three sites

Cleanup Type:
Full scale

Contaminants:
BTEX and SVOCs

- Maximum concentrations in groundwater included 2,545 ug/L for benzene; 1,383 ug/L for ethylbenzene; 3,050 ug/L for toluene; and 5,214 ug/L for xylenes

Waste Source:
Leaks from underground gasoline and fuel storage tanks and from fuel pipelines

Contact:
Naval Facilities Engineering Command
1100 23rd Avenue
Port Hueneme, CA 93043

Technology:
Pump and Treat

- Extraction includes interceptor trenches that began operating in 1996 and extraction wells, installed in April 1999 to enhance contaminant recovery in hot spot areas of the plume
- CSFF extraction system - one interceptor trench (170 ft long, 3 ft wide, 12 ft deep) with a geomembrane liner and filled with gravel, and one extraction well (PVC, 6-inch diameter, 15.5 ft deep) located upgradient of the trench; estimated pumping rate of well is 0.5 to 1 gpm
- AS-143 extraction system - one interceptor trench comprised of two legs (85 ft and 70 ft long) joined at a 130 degree angle; two extraction wells - one each located upgradient of each leg of the trench; trench and well construction similar to CSFF
- AS-4151 extraction system - one interceptor trench (185 ft long); one extraction well (28.5 ft deep); trench and well construction similar to CSFF
- Extracted water from trenches at all three sites piped to the CSFF treatment system
- Treatment system includes Stripperator® (combination oil/water separation and air stripping unit); water sent through a bag filter to granular activated carbon (GAC) units; treated effluent discharges to surface drainage; vapors from air stripper discharged to atmosphere; recovered oil stored in drums

Type/Quantity of Media Treated:
Soil and Groundwater

- Soil at site is sand, silt, and clay, underlain by fine gravel, limey clay, and shell fragments
- Water table is 6-7 ft below ground surface (bgs)

Regulatory Requirements/Cleanup Goals:

- Groundwater cleanup goals for 12 contaminants of concern including benzene (1 ug/L), ethylbenzene (29 ug/L), toluene (1,000 ug/L), xylenes (400 ug/L), 1,4-dichlorobenzene (1.8 ug/L), ethylene dibromide (0.0004 ug/L), acenaphthene (80 ug/L), acenapthylene (210 ug/L), fluorene (280 ug/L), 1-methylnaphthalene (practical quantification limit), 2-methylnaphthalene (28 ug/L), naphthalene (21 ug/L); required to treat until these goals are met or until asymptotic levels are documented
- Effluent from the CSFF treatment plant must meet the state water quality standards; NPDES permit requirements specified for benzene and toluene

Pump and Treat for the Campbell Street Fuel Farm at the Marine Corps Air Station, Camp Lejeune, North Carolina

Results:

- As of May 1999 (2.5 years of operation), the cumulative mass of contaminants removed from the three sites is 3.5 pounds, with less than 0.5 pounds removed since December 1997; installation of extraction wells at each site in April 1999 had not improved mass removal (as of May 1999)
- Influent contaminant concentrations in the CSFF and AS-4151 trenches reached asymptotic levels; during the past 20 months of operation, the mean contaminant concentrations in extracted groundwater have been < 1ug/L in the CSFF trench and not detected in the AS-4151 trench
- For the AS-143 trench, the mean contaminant concentrations in extracted groundwater was 832 ug/L during the initial months of operation, decreasing to 22 ug/L between April 1997 and March 1999; during the last six months of operation, concentrations fluctuated from not detect to 440 ug/L, with the peaks representing hot spots in the plume
- Treatment plant - from July 1996 to March 1999, the effluent has continuously exceeded discharge limits for total metals and total dissolved solids and has exceeded the lead limit 11 times

Costs:

- The capital costs to construct and prove out the system was $507,395; average annual O&M costs are $180,000
- Average cost per pound of contaminant removed is $95,000, based on 3.5 pounds of contaminant removed

Description:

The Marine Corps Air Station, which is co-located with the Marine Corps Base Camp Lejeune, North Carolina, has three areas where soil and groundwater are contaminated with BTEX and SVOCs - the CSFF site (an active fuel storage facility), Building AS-143 (an active gasoline fueling station), and Building AS-4151 (a steam generating plant). Leaks from underground gasoline and fuel storage tanks and leaks from fuel pipelines resulted in BTEX and SVOC contamination of soil and groundwater at these sites. Under the State of North Carolina UST program, the corrective action proposed for the sites included soil removal, free product recovery, pump and treat, and long-term monitoring. Contaminated soil has been excavated from each of the sites. A pump and treat system began operating at the sites in 1996.

The extraction system includes interceptor trenches and extraction wells at each site, with the extracted groundwater piped to an above ground treatment plant. The treatment plant includes oil/water separation, air stripping, and filtration. An effectiveness evaluation for the pump and treat system at this site was performed as part of a study by the Remedial Action Operation/Long Term Monitoring working group led by the Naval Facilities Engineering Service Center. The working group concluded that the overall technical performance and cost effectiveness of the system was poor. After 2.5 years of operation, cumulative mass removal for the system was only 3.5 pounds, and two of the trenches (CSFF and AS-4151) have reached asymptotic levels and are no longer removing mass. In April 1999, extraction wells were installed at each site; however, no increase in mass removal has been observed as of May 1999. The average cost per pound of contaminant removed is $95,000. Recommendations for the system include shutting down the CSFF and AS-4151 trenches; continue hot spot removal at the AS-143 site; and collect MNA data to confirm the potential for a passive remedial approach for AS-143 once the remaining hot spots have been removed.

Pump and Treat for the Eastern Groundwater Plume at the Naval Air Station, Brunswick, Maine

Site Name:
Naval Air Station Brunswick, Eastern Plume Site

Location:
New Brunswick, Maine

Period of Operation:
May 1995 to present

Cleanup Authority:
CERCLA
- ROD signed in February 1998

Purpose/Significance of Application:
Use of pump and treat to treat groundwater contaminated with chlorinated VOCs

Cleanup Type:
Full scale

Contaminants:
Chlorinated Volatile Organic Compounds (VOCs)
- 1,1-dichloroethene (1,1-DCE), 1,1-dichloroethane (DCA), cis-1,2-dichloroethene (cis-1,2-DCE), trichloroethane (TCA), tetratchloroethene (PCE), trichloroethene (TCE)

Waste Source:
Disposal of liquid wastes in the acid/caustic pit disposal area; disposal of waste fuels, oils, and degreasing solvents

Contact:
Naval Facilities Engineering Command
1100 23rd Avenue
Port Hueneme, CA 93043

Technology:
Pump and Treat
- Original extraction well network, installed in 1995, included seven wells; an eighth well was added in 1998; as of May 1999, five wells are active, including three located within the plume
- Extraction wells constructed of 6-inch diameter stainless steel, screened at varying depths ranging from 9 to 101 feet below ground surface (bgs); design pumping rate - 20 gpm per well (total system of 110 gpm)
- Monitoring well network includes three groups of wells - 13 interior plume wells; nine perimeter wells located at the edge of the plume; and 12 sentinel wells located downgradient of the plume
- Aboveground treatment - ultraviolet oxidation; metals precipitation followed by clarification and filtration (not currently in use); from May 1996 to April 1999 - average flow rate was 76 gpm, plant was operational 94-97% of the time; effluent discharged to a sanitary sewer

Type/Quantity of Media Treated:
Groundwater
- Two layers: Layer 1 - unconfined groundwater occurring within the upper stratified sand/silt unit; Layer 2 - semi-confined groundwater occurring within a lower coarse sand unit
- Hydraulic conductivity - 1×10^{-8} cm/sec

Regulatory Requirements/Cleanup Goals:
- The ROD specified cleanup levels for nine contaminants: 1,1-DCE (7 ug/L), 1,1-DCA (5 ug/L), 1,2-DCA (5 ug/L), cis-1,2-DCE (70 ug/L), trans-1,2-DCE (70 ug/L), 1,1,1-TCA (200 ug/L), 1,1,2-TCA (3 ug/L), TCE (5 ug/L), PCE (5 ug/L)
- Hydraulic containment of the plume
- Effluent must meet the Brunswick Sewer District discharge limits for 19 parameters, including metals, organics, pH, and turbidity

Results:
- As of May 1999, 536 pounds of VOCs have been removed
- In 1998, mass removal had begun to decrease; following installation of the eighth extraction well, VOC mass removal has remained steady
- Actual average annual pumping rates of individual wells ranged from 8 to 18.6 gpm, below the design rate of 20 gpm
- Treatment plant - since 1996 - two slight exceedances of discharge limits for VOCs; one exceedance of pH; consistently exceeded manganese concentrations
- Monitoring data indicate that the extent and position of the plume has not changed since the system began operating

Pump and Treat for the Eastern Groundwater Plume at the Naval Air Station, Brunswick, Maine

Costs:

- Total capital costs - $4,246,319 (including mobilization, groundwater extraction system, treatment plant, and demobilization)
- Annual O&M costs - $1,144,031(including replacement parts, labor, and chemicals)
- Average cost per pound of mass removed over time - downward trend from a high of $11,000 per pound in September 1996 to $6,200 per pound for the most recent eight months of operation (through May 1999); decrease in unit cost attributed to installation of the eighth well in a hot spot, which improved system performance

Description:

The Naval Air Station in Brunswick Maine is used to support the operation and maintenance of the P-3 Orion aircraft. The Eastern Plume of groundwater contamination is located at the eastern edge of the installation. The plume originated from three sites - the Acid/Caustic Pit (Site 4) where acid and caustic liquid wastes were disposed of in a pit; the former Fire Training Area (Site 11) where liquid wastes (oils, fuels, degreasing solvents) were used in training exercises; and the DRMO area (Site 13) where fuels and wastes were stored in USTs - resulted in groundwater contamination. A ROD for the eastern plume was signed in February 1998 and specified pump and treat as the remedy.

A groundwater pump and treat system for the Eastern Plume began operating in May 1995. The system initially included seven extraction wells, with an eighth well added in 1998 when VOC mass removal began to decrease. The treatment plant included ultraviolet oxidation. An effectiveness evaluation for the pump and treat system at this site was performed as part of a study by the Remedial Action Operation/Long Term Monitoring working group led by the Naval Facilities Engineering Service Center. As of May 1999, the system had removed 536 pounds of VOCs and the mass removal rate has been steady. According to the Navy, while the system had not experienced a significant decrease in mass removal efficiency, the price of operation has been high with an average cost per pound of mass removed of more than $7,000. The treatment plant was originally designed to handle extracted water from the Eastern Plume and water from a landfill at the installation. However, the plant was only used to treat the Eastern Plume. As a result, the capital costs significantly skewed the average cost per pound of contaminant removed, since the system had been overbuilt. Recommendations for the system include enhancing mass removal; beginning a formal evaluation of MNA; and identifying and evaluating alternatives for the discharge from the treatment plant.

Pump and Treat at the Ott/Story/Cordova Superfund Site, North Muskegon, Michigan

Site Name:
Ott/Story/Cordova Superfund Site

Location:
North Muskegon, Michigan

Period of Operation:
February 1996 - Ongoing (data available through October 2000)

Cleanup Authority:
CERCLA
- ROD issued September 29, 1990 (OU2)

EPA Remedial Project Manager:
John Fagiolo
U.S. EPA Region 5
77 West Jackson Boulevard
Chicago, Illinois 60604-3507
(312) 886-0800
(312) 886-4071 (FAX)
fagiolo.john@epa.gov

Purpose/Significance of Application:
Pump and treat of a multi-aquifer site contaminated with chlorinated and non-chlorinated VOCs and SVOCs

Cleanup Type:
Full-scale

Contaminants:
Halogenated and non-halogenated VOCs, PCBs, and pesticides
- Maximum concentrations detected in groundwater included 1,2-DCA (110,000 ug/L), 1,1-dichloroethene (DCE) (7,900 ug/L), benzene (3,800 ug/L), PCE (24,000 ug/L), toluene (38,000 ug/L), and vinyl chloride (50,000 ug/L)

Waste Source:
Disposal of industrial wastewaters and residuals from chemical production in unlined seepage lagoons

USACE Contact:
David Foster
P.O. Box 629
Grand Haven, Michigan 49417
(616) 842-5510 x17
(616) 842-6141 (FAX)
david.l.foster@usace.army.mil

Treatment System Operation Contact:
Jim Susan
Fishbeck, Thompson, Carr, and Huber
6090 East Fulton
Ada, Michigan 49301
(616) 676-3824
(616) 67605991 (FAX)

Technology:
Pump and treat (P&T) using diffused air stripping, sand filtration, and powdered activated carbon treatment (PACT)
- The site has 10 extraction wells and 90 monitoring wells
- Since 1999, the average extraction rate has been 800 gpm
- Off-gases are treated using thermal oxidation

Type/Quantity of Media Treated:
Groundwater
- An estimated 1.1 billion gallons of groundwater were treated through October 2000
- Two aquifers were identified at the site - an unconfined upper aquifer containing an upper unit and a lower unit, and a lower aquifer

Regulatory Requirements/Cleanup Goals:
- The ROD identified cleanup levels for 19 constituents in groundwater, including VOCs and SVOCs
- EPA selected TOC as an indicator compound for organic contaminants at the site
- Treated groundwater was required to meet discharge criteria in an NPDES permit

Results:
- Groundwater monitoring data shows that progress is being made towards meeting the cleanup goals. As of October 2000, cleanup goals have been met for all contaminants in 27 of the 52 wells sampled.
- TOC concentrations in the area of highest contamination have decreased in the upper unit of the unconfined upper aquifer and in the lower aquifer; TOC concentrations have remained relatively constant in the lower unit of the upper unconfined aquifer.
- Available data on the treatment system (through December 1999) showed that NPDES permit limits were being met for discharge to the river

Costs:
- Since startup, 1.1 billion gallons of groundwater have been treated by the remedial system which cost a total (capital plus operating) of $32,123,500, which is equivalent to $30 per thousand gallons of groundwater treated

Pump and Treat at the Ott/Story/Cordova Superfund Site, North Muskegon, Michigan

Description:
The Ott/Story/Cordova Superfund Site, in North Muskegon, Michigan, was used for manufacturing a variety of organic chemicals. In the early 1960s, soil and groundwater contamination were discovered at the site, including VOCs and SVOCs. More than 90 contaminants were identified in the groundwater, including benzene, toluene, chlorobenzene, methylene chloride, chloroform, 1,1-dichloroethane (DCA), 1,2-DCA, vinyl chloride, and tetrachloroethene (PCE), PCBs, heptachlor epoxide, zinc, copper, and nickel. A ROD for aquifer restoration at this site (OU 2) was signed September 29, 1990.

Groundwater at the site is treated using pump-and-treat using diffused air stripping, sand filtration, and PACT, and monitoring data show that progress is being made towards meeting the cleanup goals, however all cleanup goals have not yet been met. Since startup, 1.1 billion gallons of groundwater have been treated by the remedial system which cost a total (capital plus operating) of $32,123,500, which is equivalent to $30 per thousand gallons of groundwater treated. According to the RPM, there is no longer a visible sheen where groundwater flows into a local creek and the groundwater treatment facility has achieved the NPDES discharge permit limitations throughout its operation.

IN SITU GROUNDWATER TREATMENT ABSTRACTS

Air Sparging/Soil Vapor Extraction at Eaddy Brothers, Hemingway, South Carolina

Site Name:
Eaddy Brothers

Location:
Hemingway, SC

Period of Operation:
July 1999 - present (data available through August 2000)

Cleanup Authority:
RCRA UST

Purpose/Significance of Application:
Use of air sparging/soil vapor extraction to treat MTBE in soil and groundwater

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX, Naphthalene
- MTBE concentrations as high as 5,110,000 ug/L
- BTEX concentrations as high as 301,000 ug/L for toluene
- Naphthalene concentrations as high as 2,700 ug/L

Waste Source:
Leaks from an underground gasoline storage tank

State Contact:
Read S. Miner, P.G.
Hydrogeologist
South Carolina Dept. of Health and Environmental Control
2600 Bull St.
Columbia, SC 29201
Telephone: (803) 898-4350
Fax: (803) 898-4330
E-mail:
minerrs@columb26.dhec.state.sc.us

Contractor:
Consultech Environmental, Inc.
1800 MacLeod Dr., Suite F
Lawrenceville, GA 30043
Telephone: (678) 377-0400
Fax: (678) 377-0051
www.consultechenv.com

Technology:
Air Sparging/Soil Vapor Extraction (SVE)
- SVE system consists of approximately 230 feet of horizontal SVE piping installed immediately below the asphalt parking lot surface of the site; piping is connected to a 20 HP Lamson Blower operating at 12 to 14 inches of mercury; extracted vapors are treated using a thermal oxidizer.
- Air sparging system, which began operating two weeks after the SVE system was activated, consists of ten vertical air sparging wells, each installed at a depth of about 26 feet with 5-foot well screens; wells are connected to a Kaeser SK-26 air sparge compressor operating at 68 to 70 psi.
- A total of 28 wells (on-and off-site) are used to monitor groundwater

Type/Quantity of Media Treated:
Soil and Groundwater
- Soil at the site consists of silty clays with inter-fingered thin clayey-sand lenses; no confining units identified
- Average hydraulic gradient is 0.005 feet/feet with a calculated seepage velocity of 0.138 feet per year
- Depth to groundwater is 2.5 to 17.9 feet below ground surface (bgs)

Regulatory Requirements/Cleanup Goals:
- Site-specific target levels (SSTLs) were established by SCDHEC for MTBE, benzene, toluene, ethylbenzene, xylenes, and naphthalene, with 15 monitoring wells used in setting the SSTLs.
- Total SSTLs (sum of individual SSTLs for each well) - MTBE - 646 ug/L; benzene - 191 ug/L; toluene - 11,938 ug/l; ethylbenzene - 9,426 ug/L; xylenes - 78,496 ug/L; naphthalene -418 ug/L

Results:
- As of August 2000, the total mass and maximum concentrations of MTBE, BTEX constituents, and naphthalene in the groundwater had decreased, with the SSTLs being met for toluene, ethylbenzene and xylenes.
- Total MTBE concentrations have been reduced by about 99.99 %; BTEX concentrations by more than 99%, and naphthalene concentrations by about 96%; the SSTLs had not been met for benzene, MTBE, or naphthalene
- The system will continue to be operated until all SSTLs have been met; the contractor projects cleanup of the site to be completed by April 2001

Costs:
- The total cost for the cleanup of this site is $197,515.
- The South Carolina Petroleum Cleanup Fund awarded the contract for the cleanup at this site as a fixed-price, lump sum with no change orders; no additional information on cost breakdown was available.

Air Sparging/Soil Vapor Extraction at Eaddy Brothers, Hemingway, South Carolina

Description:
Eaddy Brothers is a gasoline service station located in Hemingway, South Carolina. In September 1998, a release was reported from the station's underground storage tanks (USTs). Initially, the local fire department was dispatched in an emergency response because of gasoline vapors that had accumulated in a storm sewer underlying downtown Hemingway. Soil and groundwater at the site were found to be contaminated with MTBE, BTEX, and naphthalene, and free product was present in the groundwater. Data from October 1998 showed concentrations of contaminants in groundwater as high as 5,110,000 ug/L for MTBE, 226,000 ug/L for benzene, 301,000 ug/L for toluene, 280,000 ug/L for ethylbenzene, 278,000 ug/L for xylene, and 2,700 ug/L for naphthalene. A Corrective Action Plan (CAP) was implemented in July 1999 under Subtitle I of the RCRA program. The CAP included free product recovery and treatment of dissolved-phase groundwater contamination using air sparging/SVE.

The SVE system, installed in July 1999, consists of a 230-foot horizontal SVE pipe installed immediately below the asphalt parking lot surface of the site, with extracted vapors treated using a thermal oxidizer. The air sparging system, which began operating two weeks after the SVE system was activated, consists of ten vertical air sparging wells. After about a year of operation of the air sparging/SVE system, the SSTLs have been met for toluene, ethylbenzene, and xylenes. While MTBE, benzene, and naphthalene levels have been reduced by more than 90%, they remain above the SSTLs. The system will continue to operate until all SSTLs have been met, with the site contractor estimating completion of the remediation in April 2001.

Air Sparging at Four Sites

Site Names:
Multiple Locations (site names confidential)

Locations:
Service station, Pensacola, Florida
Fuel station, Albuquerque, New Mexico
Service station, Sebato, Maine
Service station, Massachusetts (city not provided)

Period of Operation:
1993 to 1995
- Florida site (3/94 to 7/94); New Mexico site (6/93 to 1/95); Maine site (4/94 to 10/95); Massachusetts site (operated for 21 months; dates not provided)

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Air sparging used to treat MTBE in groundwater

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX
- MTBE concentrations at the sites ranged from 215 ug/L to 62,000 ug/L in groundwater
- BTEX concentrations at the sites ranged from 64 ug/L to 198,000 ug/L in groundwater

Waste Source:
Leaks from gasoline storage tanks

Vendor:
Nick Hastings/David Bass
IT Corporation
431-F Hayden Station Road
Windsor, CT 06095
Telephone: (860) 688-1151
Fax: (860) 688-8239
E-mail: nhastings@theitgroup.com

Technology:
Air Sparging
- Number of air sparging wells at the four sites ranged from 4 to 9, with well spacings ranging from 25 to 50 feet (ft) and flow rates of wells ranging from 5 to 10 scfm
- One of the systems was pulsed on a daily cycle; the others sparged on a continuous basis
- For three sites, the air sparging wells were located over the source area; for one site, the air sparging wells were arrayed at points located downgradient from the source

Type/Quantity of Media Treated:
Groundwater
- Sand to fine sand aquifers at three of the sites (Florida, New Mexico, Maine); not reported for Massachusetts site
- Depth to groundwater about 40 feet below ground surface at New Mexico site; not reported for other sites

Regulatory Requirements/Cleanup Goals:
Information about specific cleanup goals for each site was not provided

Results:
- For four sites, the reduction in MTBE concentrations at shutdown ranged from greater than 99% to 46.5%
- Post-closure monitoring for MTBE, performed at three sites, showed reductions that ranged from greater than 97.8% to 99.97% ug/L
- At the Florida site, air sparging reduced the concentration of MTBE in the groundwater to <5 ug/L, with no rebound after 6 months of post-closure monitoring
- At the New Mexico site, MTBE concentrations were reduced to 27 ug/L, with the concentration further reduced to 8 ug/L after 13 months of post-closure monitoring
- At the Maine site, MTBE concentrations were reduced to between 16 and 980 ug/L, and the concentration was further reduced to ND - 115 ug/L after 6.5 months of post-closure monitoring
- At the Massachusetts site, MTBE was reduced to 115 ug/L (a 46.5% reduction); no rebound was reported for this site

Costs:
No cost data were provided for these sites

Air Sparging at Four Sites

Description:
Air sparging was used to treat groundwater contaminated with gasoline from leaking storage tanks at the following four sites - a service station in Pensacola, Florida, a fuel station in Albuquerque, New Mexico, a service station in Sebato, Maine, and a service station in Massachusetts. Contaminants found in the groundwater included MTBE and benzene, toluene, ethylbenzene, and xylenes (BTEX) at two sites, MTBE, BTEX, and gasoline at one site, and MTBE and benzene at one site. The number of air sparging wells at the four sites ranged from 4 to 9, with well spacings ranging from 25 - 50 feet (ft) and flow rates of wells ranging from 5 - 10 scfm. One of the systems was pulsed on a daily cycle and the others sparged on a continuous basis. The duration of the projects ranged from 4 to 21 months.

Information on specific cleanup goals for each site was not provided. Air sparging reduced the concentration of MTBE in the groundwater to <5 ug/L, with no rebound after 6 months of post-closure monitoring at the Florida site; to 27 ug/L at the New Mexico site, with the concentration further reduced to 8 ug/L after 13 months of post-closure monitoring; to between 16 and 980 ug/L at the Maine site, with the concentration further reduced to ND - 115 ug/L after 6.5 months of post-closure monitoring; and to 115 ug/L at the Massachusetts site, with no rebound reported. According to the vendor, *in situ* air sparging also can be applied in combination with bioaugmentation for rapid initial mass removal by volatilization followed by removal via aerobic biodegradation (where air sparging becomes the oxygen delivery vehicle).

Air Sparging and Soil Vapor Extraction at the Mound Plant OU 1 Site, Miamisburg, Ohio

Site Name:
Mound Plant OU 1 Site

Location:
Miamisburg, OH

Period of Operation:
Ongoing (Data available from December 1997 to May 2000)

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Full-scale treatment of chlorinated solvents using air sparging and soil vapor extraction

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents
- Primary VOCs in soil (vadose zone) were tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (DCE), toluene, ethylbenzene, and xylenes
- Concentrations in soil generally ranged from 0.001 to 14.4 mg/kg; one well had a concentration of 8,619 mg/kg
- Primary VOCs in groundwater were PCE, TCE, DCE, VC, and trichloromethane
- Concentrations in groundwater ranged from 10 to 1,200 ug/L, with an average of 101 ug/L

Waste Source:
Disposal of wastes in landfills

Site Contact:
Monte Williams
BWXTO Mound OU 1 ER
DOE Miamisburg Environmental Project Office (MEMP)
Phone: (937) 865-4543

Technical Contacts:
Gary Brown
DOE ITRD Program
Sandia National Laboratories
Phone: (505) 845-8312
E-mail: gbrown@sandia.gov

Mark Spivey
BWXTO Mound OU 1
Phone: (937) 865-3709

Technology:
Air Sparging and Soil Vapor Extraction (AS/SVE)
- Equipment included 23 air injection wells, 10 extraction wells, and 5 French drains
- Air was pumped into the aquifer through the injection wells, and removed as soil vapor from the extraction wells and French drains
- The air sparge system operated at 15 cfm from December 1997 to February 1998, and then shut down due to screen fouling
- The SVE system removed soil gas at rates ranging from 475 to 625 scfm, and operated at a relatively high vacuum (13 inches Hg)
- Extracted vapors were treated with carbon prior to release to the atmosphere

Type/Quantity of Media Treated:
Soil and Groundwater
- Bedrock at the site is overlain by 15-20 ft of glacial outwash materials, primarily gravel and sandy gravel; the aquifer is contained in the outwash materials, varies from 0 - 40 ft thick, and is relatively free of fine-grained till layers
- Hydraulic gradients are nearly flat
- A surficial deposit ranging from 24 - 31 ft thick, composed of glacial till and artificial fill, caps the site - the till and fill are silty clay to sandy clay
- Vadose zone contamination occurs at a depth of less than 20 ft.

Regulatory Requirements/Cleanup Goals:
- Objectives included removing chlorinated VOCs from the soil and groundwater, and estimating the time needed to meet cleanup goals
- Specific cleanup goals were not identified

Results:
- As of May 2000, 3,433 lbs of VOCs had been removed, and the total VOC concentrations in the unsaturated zone decreased from 618.1 to 4.54 mg/kg
- The site was projected to meet cleanup goals by December 2002

Air Sparging and Soil Vapor Extraction at the Mound Plant OU 1 Site, Miamisburg, Ohio

Costs:

- The total cost for AS/SVE was $1,439,039, consisting of $116,773 for pilot testing, $221,591 for design, $398,000 for construction, $517,958 for operations, and $184,717 for sampling and analysis
- As of May 2000, the overall unit cost was $420 per pound of contaminant removed

Description:

The Mound Plant is a government-owned and contractor-operated facility occupying a 306-acre site within the city of Miamisburg, Ohio. The OU 1 site occupies three acres on the western edge of the developed portion of the facility. The historic landfill in OU 1 was used between 1948 and 1974 for disposal of general trash and liquid wastes from Mound Plant operations. The sanitary landfill in OU 1 was constructed partially within and adjacent to the location of the historic landfill. Both disposal sites have been used for dumping, burning, moving, reworking, and burying various plant wastes. A periodic water sampling program and a Phase 1 investigation indicated that VOCS were present in the soil and groundwater at OU 1.

An air sparging and soil vapor extraction (AS/SVE) system began operating at OU 1 in December 1997. The system was intended to remove chlorinated VOCs from the soil and groundwater at the site. After 2 ½ years of operation, 3,433 lbs of VOCs had been removed, and the total VOC concentrations in the unsaturated zone decreased from 618.1 to 4.54 mg/kg. If system performance is maintained, the site was projected to meet cleanup goals by December 2002. The total cost for AS/SVE at this site was $1,439,039.

Air Sparging at Former Nu Look One Hour Cleaners, Coral Springs, Florida*

Remediation Technology

- Air Sparging utilizing Recirculation Well (in-well stripping) - NoVOCsTM

Site Description

- This is an inactive drycleaning facility that utilized PCE and operated from 1991 - 1999. The facility is in a strip shopping center in a mixed commercial/residential setting.

Site Hydrogeology

- Depth to Water: 4 ft. bls.
- Unconfined Aquifer
- Lithology: surface - 7 ft. bls: organic rich, fine-grained sand & peat
  7 - 19 ft. bls.: limestone interbedded with shell hash and fine-grained sand
  19 - 30 ft. bls.: silty fine-grained sand with minor clay
  30 - 55 ft. bls.: fine-grained sand
  55 - 58 ft. bls.: dense fine-grained sandstone
- Hydraulic Gradient: 0.00095 ft./day
- Hydraulic Conductivity: 12.6 ft./day
- Seepage Velocity: 0.03 ft./day

Groundwater Contamination

- Contaminants Present: PCE, TCE, cis 1,2-DCE, trans 1,2-DCE, vinyl chloride
- Highest Concentrations: 1990 μg/l PCE, 11,700 μg/l TCE, 10,200 μg/l cis 1,2-DCE, 5.5 μg/l trans 1,2-DCE, 1000 μg/l vinyl chloride
- Deepest Contamination: 56 ft. bls.
- Contaminant Plume Size: 1.25 acres

Remediation Scenario

- A single pilot recirculating well using in-well airlift through a 12 foot stripping column was operated for a period of 30 days. Air was introduced through a diffuser at an average rate of 35 cfm. and 5 psig. This correlated to a theoretical groundwater flow rate of approximately 5 gpm.

- System was operated in "closed loop" configuration, i.e. air/vapor stream extracted from wellhead is recycled through carbon treatment system for reuse in airlift stripping column. This minimized the re-injection of oxygen into the recirculation loop and allowed in-situ contaminants to continue natural degradation in an anaerobic environment.

Results

- The single pilot well achieved an average radius of influence of 62 ft. in the surficial aquifer based upon a 75% reduction of total VOHs based on groundwater sampling from monitor wells. Tracer tests indicated groundwater particles traveled approximately 20 ft. down-gradient in 130 minutes, 20 ft. up-gradient in approximately 180 minutes and approximately 30 ft. cross-gradient in 360 minutes. The estimated average radius of influence based upon tracer testing was 25 ft.

- 99% reduction of VOHs in source area after 30 days treatment.

- Elimination of 1000 μg/l contour of dissolved contamination and slight downgradient shift of 100 μg/l contour of dissolved contamination. No shift in 1 μg/l contour of dissolved contaminants.

- Slight rebound of PCE concentrations at source well six months after completion of pilot test. Also slight rebound of cis 1,2-DCE and vinyl chloride concentrations at downgradient wells 6-12 months following completion of pilot tests.

Air Sparging at Former Nu Look One Hour Cleaners, Coral Springs, Florida*

Costs

- Overall Project Cost - $ 193,000
- Well Installation Cost - $16,000

Lessons Learned

1. No water use permit required since contaminated water is neither pumped nor treated above ground.

2. Vertical gradients induced in recirculation zone appear to enhance physical removal of contaminants from low permeability zones.

3. Presence of organic rich sand and peat possibly enhanced remediation by circulating naturally occurring organic carbon (food source) into treatment zone.

4. Iron bacteria fouling of well screens necessitated the incorporation of additional measures aimed at eliminating bio-fouling at discharge zone. Bio-fouling resulted in major operational and maintenance problems. Assessing the impact of groundwater geochemistry upon the system is important.

Contacts

Florida Dept. of Environmental Protection: Brent Hartsfield (850) 488-0190
Metcalf & Eddy: Bruce Koenig (954) 450-5201

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* This is the complete report provided by the State Coalition of Dry Cleaners (*www.drycleancoalition.org*) for this project. A separate abstract for this project is not available.

Air Sparging/Soil Vapor Extraction and Multi-Phase Extraction at Scotchman #94, Florence, South Carolina

<table>
<tr><td colspan="2">**Site Name:**
Scotchman #94</td><td>**Location:**
Florence, SC</td></tr>
<tr><td colspan="2">**Period of Operation:**
April 1998 - present (data available through March 2000)</td><td>**Cleanup Authority:**
RCRA UST</td></tr>
<tr><td colspan="2">**Purpose/Significance of Application:**
Use of multiphase extraction and air sparging/soil vapor extraction to treat MTBE in soil and groundwater</td><td>**Cleanup Type:**
Full scale</td></tr>
<tr><td colspan="2">**Contaminants:**
MTBE, BTEX, Naphthalene
• MTBE concentrations as high as 87,000 ug/L in groundwater
• BTEX concentrations as high as 140,000 ug/L for toluene in groundwater
• Naphthalene concentrations as high as 4,600 ug/L in groundwater</td><td>**Waste Source:**
Leaks from an underground gasoline storage tank</td></tr>
<tr><td rowspan="2">**Site Contact:**
Worsley Companies, Inc.
P.O. Box 3227
Wilmington, SC 28406
Telephone: (910) 395-5300

State Contact:
Kimberly Wilson, P.G.
Hydrogeologist
South Carolina Dept. of Health and Environmental Control
2600 Bull St.
Columbia, SC 29201
Telephone: (803) 898-4350
Fax: (803) 898-4330
E-mail:
wilsonka@columb26.state.sc.us

Contractor:
CBM Environmental
P.O. Box 411387
Charlotte, NC 28241
Telephone: (800) 743-1226
Fax: (803) 548-5892
E-mail: cbm@celink.net</td><td colspan="2">**Technology:**
Multi-Phase Extraction (MPE) and Air Sparging/Soil Vapor Extraction (SVE)
• MPE system consisting of five extraction (recovery) wells
• Air sparging/SVE system includes 28 air sparging wells, arranged in seven groups of air sparging wells
• A total of 19 monitoring wells at the site, installed at depths ranging from 14 to 30 feet below ground surface (bgs); each well includes a 10-foot screened interval, with the depths of the screened intervals ranging from about 10 to 27.5 feet bgs.</td></tr>
<tr><td colspan="2">**Type/Quantity of Media Treated:**
Soil and Groundwater
• Soil at the site consists of clayey sands and sandy-clays; hard clay layer is present at approximately 10 feet bgs
• Average hydraulic gradient is 0.004 feet/feet with a calculated seepage velocity of 4.415 feet per year
• Depth to groundwater is 5.4 to 23 feet bgs</td></tr>
<tr><td colspan="3">**Regulatory Requirements/Cleanup Goals:**
• Site-specific target levels (SSTLs) were established by SCDHEC for MTBE, benzene, toluene, ethylbenzene, and xylenes, and naphthalene, with seven monitoring wells (MW-1, MW-2, MW-6, MW-11, MW-15, MW-18, MW-19) and outfall OS-1 used in setting the total SSTLs
• Total SSTLs (sum of individual SSTLs for each well) - MTBE - 7,700 ug/L; benzene - 957 ug/L; toluene - 119,250 ug/l; ethylbenzene - 37,082 ug/L; xylenes - 187,511 ug/L; naphthalene - 2,808 ug/L</td></tr>
</table>

Air Sparging/Soil Vapor Extraction and Multi-Phase Extraction at Scotchman #94, Florence, South Carolina

Results:
- MTBE concentrations in the groundwater decreased through December 1999 to 17,736 ug/L, then increased to more than 192,000 ug/L in March 2000
- Similar trends were observed for BTEX constituents and naphthalene, with total mass decreasing through December 1999, then increasing in March 2000
- Decreases in the maximum concentrations (as measured in an individual well) were observed for each of the constituents. For example, maximum MTBE concentrations were reduced from 37,000 ug/L to 9,800 ug/L (about 74%), and concentrations of benzene from 14,000 ug/L to 1,300 ug/L (91%).
- As of March 2000, all constituents remained above the SSTLs; and operations will continue until all SSTLs have been met.
- According to the contractor, cleanup of the site is projected to be completed by March 2001.

Costs:
- The total cost for the cleanup of this site is $383,000.
- The South Carolina Petroleum Cleanup Fund awarded the contract for the cleanup at this site as a fixed-price, lump sum with no change orders; no additional information on cost breakdown was available.

Description:
Scotchman #94 is a gasoline service station located in Florence, South Carolina. In December 1991, a release was reported from the station’s underground storage tanks (USTs), and soil and groundwater at the site were found to be contaminated with MTBE, BTEX, and naphthalene, and free product was present in the groundwater. Contaminants in groundwater were found to be as high as 87,000 ug/L for MTBE, 23,000 ug/L for benzene, 140,000 ug/L for toluene, 18,000 ug/L for ethylbenzene, 91,000 ug/L for xylenes, and 4,600 ug/L for naphthalene. A Corrective Action Plan (CAP) was implemented in March 1999 under Subtitle I of the RCRA program, which included free product recovery using MPE and treatment of dissolved-phase groundwater contamination using air sparging/SVE.

The MPE system consists of five extraction (recovery) wells and the air sparging/SVE system includes 28 air sparging wells, arranged in seven groups of air sparging wells. MTBE, BTEX, and napthalene levels initially decreased through December 1999, then increased. After two years of operation, all constituents remained above the SSTLs. The system will continue to be operated until the SSTLs are met (projected completion in March 2001).

In Situ Bioremediation at Brownfield Site, Chattanooga, Tennessee

Site Name:
Brownfield Site (actual site name confidential)

Location:
Chattanooga, TN

Period of Operation:
January 1999 to present (data available through December 1999)

Cleanup Authority:
January 1999 to present (data available through December 1999)

Purpose/Significance of Application:
Use of *in situ* bioremediation to treat MTBE in groundwater

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX, TPH
- MTBE concentrations as high as 5,000 ug/L
- BTEX concentrations as high as 8,000 ug/L
- TPH concentrations as high as 300,000 ug/L
- Plume containing MTBE and benzene covers approximately 16,000 square feet; TPH plume covers approximately 66,000 square feet (1.5 acres)

Waste Source:
Leaks from an underground gasoline storage tank

Project Contact:
Mark B. Miller, P.G.
Remedial Solutions, Inc.
2733 Kanasita Drive, Suite A
Hixson, TN 37343
Telephone: (423) 870-8888
E-mail: remsol@cdc.net

Vendor:
Brian L. Clark, P.E.
Executive Vice President
Enzyme Technologies, Inc.
5228 NE 158th Avenue
Portland, OR 97230
Telephone: (503) 254-4331 x11
Fax: (503) 254-1722
E-mail: brianc@enzymetech.com

Technology:
In Situ Bioremediation
- *In situ* bioremediation using the Enzyme-Catalyzed *In Situ* Dissolved Oxygen Treatment (DO-IT) process; patented process uses a combination of proprietary multi-enzyme complexes (proteins that are extracted from living TPH-degrading bacterial cultures), and a consortium of total petroleum hydrocarbon (TPH) degrading bacteria, with supplemental oxygen; generates a concentration of dissolved oxygen in water of approximately 40 mg/L
- Three horizontal injection wells, two vertical injection wells, and three extraction/recovery wells were installed within the plume
- Groundwater was extracted from down-gradient locations, amended by adding oxygenated water, nutrients, and the enzyme/bacterial consortium mixture, and then re-injected using the horizontal and vertical injection wells; layout provided for both treatment and hydraulic control
- Initial inoculation in January 1999 consisted of approximately 75 gallons of enzymes and 150 gallons of bacteria; each month, 5 gallons of enzymes and 10 gallons of bacteria have been added to the oxygenated water to maintain the microbial population

Type/Quantity of Media Treated:
Groundwater
- On-site groundwater is located within a tight clay soil horizon at 5-7 feet below ground surface (bgs)
- Off-site groundwater is located in bedrock consisting of limestone and shale beds at depths of greater than 10 feet bgs

Regulatory Requirements/Cleanup Goals:
- The cleanup criteria specified for this site were benzene - 100 mg/kg in soil and 70 ug/L in groundwater, and TPH - 1,000 mg/kg in soil and 1,000 ug/L in groundwater
- No cleanup levels were specified for MTBE, however MTBE was identified as a contaminant of concern for the site

Results:
- Results were available for the first 360 days of operation (January to December 1999) from well MW-2 (the well with the highest concentrations of contaminants)
- MTBE concentrations were reduced from approximately 5,000 ug/L to approximately 200 ug/L
- Benzene concentrations were reduced from as high as 8,000 ug/L to less than approximately 1,000 ug/L
- TPH concentrations were reduced from as high as 300,000 ug/L to less than approximately 50,000 ug/L
- Benzene and TPH concentrations remain above cleanup goals; treatment system operation is ongoing

In Situ Bioremediation at Brownfield Site, Chattanooga, Tennessee

Costs:

- Start-up costs for this site, including the initial inoculation, were approximately $30,000
- Monthly maintenance costs have been approximately $4,000, through December 1999

Description:

As a result of leaking underground storage tanks (USTs), gasoline, diesel fuel, and waste oil releases occurred at an abandoned gasoline service station located in a mixed-use area in Chattanooga Tennessee. The service station has no remaining on-site structures or facilities. The releases resulted in contamination of soil and groundwater at the site with MTBE, BTEX, and petroleum constituents. Concentrations of contaminants measured in groundwater at the site were as high as MTBE at 5,000 ug/L, benzene at 8,000 ug/L, and total petroleum hydrocarbons at 300,000 ug/L. The vendor estimated that 1,500 cubic yards of soil at the site were impacted by the contamination. In the mid-1990s, the USTs were removed and decommissioned.

Beginning in January 1999, *in situ* bioremediation using the Enzyme-Catalyzed *In Situ* Dissolved Oxygen Treatment (DO-IT) process was used to treat groundwater at the site. This process uses a combination of proprietary multi-enzyme complexes and a consortium of total petroleum hydrocarbon (TPH) degrading bacteria, with supplemental oxygen, to biodegrade MTBE, BTEX, and TPH contaminants. At this site, three horizontal injection wells, two vertical injection wells, and three extraction/recovery wells were installed within the plume. In January 1999, the initial inoculation of approximately 75 gallons of enzymes and 150 gallons of bacteria was performed. Subsequently, 5 gallons of enzymes and 10 gallons of bacteria have been added to the oxygenated water each month to maintain the microbial population. As of December 1999, after 360 days of operation, the concentrations of MTBE, BTEX, and TPH have been reduced by more than 70%. However, cleanup goals were not reached for benzene or TPH in the groundwater during this time, and treatment is ongoing. The technology vendor reported that this application was aided by the design of injection galleries that were specific to the low permeability of the soil formation and the intended injection approach.

In Situ Bioremediation at Cordray's Grocery, Ravenel, South Carolina

Site Name:
Cordray's Grocery

Location:
Ravenel, SC

Period of Operation:
April 1998 to July 2000 (data available through January 2000)

Cleanup Authority:
RCRA UST

Purpose/Significance of Application:
Use of *in situ* bioremediation using ORC® to treat MTBE in groundwater

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX, Naphthalene

- MTBE concentrations as high as 2,230 ug/L
- BTEX concentrations as high as 28,600 ug/L for toluene
- Naphthalene concentrations as high as 134 ug/L

Waste Source:
Leaks from an underground gasoline storage tank (UST)

Site Contact:
Youman's Gas & Oil
P.O. Box 399
Hollywood, SC 29449
Telephone: (843) 889-2212

State Contact:
Scott McInnis
South Carolina Dept. of Health and Environmental Control
2600 Bull Street
Columbia, SC 29201
Telephone: (803) 898-4350
Fax: (803) 898-4330
E-mail:
mcinniwa@columb26.dhec.state.sc.us

Vendor:
John Albrecht, President
Director, Assessment/Remediation
Albrecht & Associates
P.O. Box 189
Mt. Pleasant, SC 29465
Telephone: (843) 856-8450
Fax: (843) 856-8453
E-mail:
JHA@albrechtenvironmental.com

Technology:
In Situ Bioremediation using ORC®

- The UST was removed and soil was excavated in two areas at the site prior to application of ORC®
- A total of 140 lbs of ORC® was injected in the excavated areas
- The one time application of ORC® was performed on August 31, 1998, with an injection depth of 20 - 25 feet (ft) below ground surface (bgs)
- Seven monitoring wells were located around the excavation areas

Type/Quantity of Media Treated:
Groundwater

- Average depth to groundwater is 9 feet below ground surface (bgs)
- Average hydraulic gradient is 0.006 ft/ft with a calculated seepage velocity of 0.473 feet per year

Regulatory Requirements/Cleanup Goals:

- Site-specific target levels (SSTLs) were established by SCDHEC for MTBE, BTEX constituents (benzene, toluene, ethylbenzene, and xylenes), and naphthalene
- SSTLs for well MW-0 were: MTBE - 239 ug/L; benzene - 4,150 ug/L; toluene - 21,400 ug/L; ethylbenzene - 1,700 ug/L; xylenes - 11,700 ug/L; and naphthalene - 557 ug/L
- SSTLS for well MW-5 were: MTBE - 115 ug/L; benzene - 4,020 ug/L; toluene -2,900 ug/L; ethylbenzene - 460 ug/L; xylenes - 2,380 ug/L; and naphthalene - 170 ug/L

In Situ Bioremediation at Cordray's Grocery, Ravenel, South Carolina

Results:

- According to SCDHEC, cleanup goals at the site were met in November 1998
- Results of the January confirmation sampling event showed that the SSTLs had been met for MTBE, BTEX, and naphthalene in wells MW-0 and MW-5, with concentrations of MTBE and naphthalene below detection limits in both wells
- Concentrations of BTEX constituents were reduced by 99% in well MW-5, and by as much as 95% (benzene) in well MW-0
- The SCDHEC reported that the corrective action was completed on July 24, 2000.

Costs:

- The total cost for the cleanup at this site was $21,000
- The South Carolina Petroleum Cleanup Fund awarded the contract for the cleanup at this site as a fixed-price, lump sum with no change orders; no additional information on cost breakdown was available.

Description:

The Cordray's site is the location of a former gasoline service station. In 1987, leaks from a gasoline underground storage tank (UST) resulted in contamination of soil and groundwater at the site with MTBE, BTEX, and naphthalene. A 550-gallon UST was removed in 1987 and a Corrective Action Plan (CAP) was implemented in April 1998 under Subtitle I of the RCRA program. The CAP included excavation of soil and *in situ* bioremediation of groundwater using ORC®. Soils were excavated in two areas, with ORC® injected into the excavated areas.

On August 31, 1998, a one time application of 140 lbs. of ORC® was performed in the excavated areas, at an injection depth of 20 - 25 ft bgs. Cleanup goals at the site were met in November 1998, and confirmed during a January 1999 confirmation sampling event. Concentrations of MTBE and naphthalene were reduced to below detection limits in wells MW-0 and MW-5; concentrations of BTEX constituents were reduced by 99% in well MW-5, and by as much as 95% in well MW-0. According to SCDHEC, the corrective action was completed on July 24, 2000. In addition, the SCDHEC indicated that the cleanup was completed within the predicted time, and the use of a fixed price contract (total cost of $21,000) was less costly than a time and materials contract.

In Situ Bioremediation at Contemporary Cleaners, Orlando, Florida*

Remediation Technology

- In-Situ Bioremediation - Hydrogen Release Compound (HRC) - Regenesis Bioremediation Products, Inc.

Site Description

- This is an active Perchloroethene (PCE) drycleaning facility that has been in operation since 1974. It is located in a shopping center in a commercial setting.

Site Hydrogeology

- Depth to Water: 6-8 ft below land surface (bls)
- Upper Surficial Aquifer: 25-30 ft of fine-grained quartz sand
  Hydraulic Gradient: 0.01 ft/ft
  Hydraulic Conductivity: 1.3 ft/day
  Seepage Velocity: 0.04 ft/day
- 1 - 12 ft of clay
- Lower Surficial Aquifer: 20 - 25 ft of fine-grained silty sand and sandy clay
  Hydraulic Gradient: 0.003 ft/ft
  Hydraulic Conductivity: 65 ft/day
  Seepage Velocity: 1 ft/day

Groundwater Contamination

- Contaminants Present: PCE, TCE, cis 1,2-DCE, trans 1,2-DCE, vinyl chloride
- Highest Contaminant Concentrations: 3300 μg/l PCE, 4,980 μg/l TCE, 4000 μg/l cis 1,2-DCE, 130 μg/l trans 1,2-DCE, 2,900 μg/l vinyl chloride
- Deepest Contamination: 54 ft bls. Plume Size: 3.2 acres (as defined to regulatory MCLs)

Remediation Scenario

- Treatment Area: 14,600 ft2 (within PCE 1 mg/L isopleth)- Upper Surficial Aquifer
- Quantity: 6,810 lb of HRC
- Injection: By direct push technology at 144 locations, spaced on 10-ft centers. (80 ft x 180 ft grid) at depths from 5 - 30 ft bls
- Volume: 2.45 gal of HRC (22.5 lb Or 0.9 lb/ft)/per injection point

Results

- % Mass Reduction (after 152 days) - based on groundwater monitoring:
  PCE - 96%   cis 1,2-DCE - 36%
  TCE - 51%   vinyl chloride - 58%

Costs

- Overall Project = $ 127,000
- HRC product = $ 27,197

Lessons Learned

1. Underground Injection Control variance required.

2. Recommend requiring complete delineation of underground utilities prior to injection activities. Use of geophysical survey (GPR and electrical methods) is very helpful to ensure underground utilities are not encountered or damaged during injection.

In Situ Bioremediation at Contemporary Cleaners, Orlando, Florida*

3. A thorough understanding of site geochemistry is required to understand effect of HRC on groundwater. Acids released form the breakdown of HRC appeared to lower the pH of groundwater in certain portions of the aquifer to levels that were not conducive to continued reductive dechlorination of contaminants. The problem appears to be transient, as the pH continues to increase over time. Reformulation (reduction in concentration) of HRC should minimize this problem. The buffering capacity of the predominantly quartz sand aquifers is limited in the presence of excess acids produced from HRC. Aquifers with different sediment composition will respond differently to the HRC.

4. Prior to injection, the containers of HRC were warmed by placing them in the boiler room of the drycleaning facility. This reduced the HRC viscosity and facilitated injection.

5. Regenesis offers design and onsite assistance and instruction during injection activities. Their guidance was very useful during the initiation of the project.

Contacts

Florida Department of Environmental Protection: Judie Kean (850) 488-0190
International Technology Corporation: Mike Lodato (813) 626-2336

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* This is the complete report provided by the State Coalition of Dry Cleaners (*www.drycleancoalition.org*) for this project. A separate abstract for this project is not available.

In Situ Bioremediation at Gas Station, Cheshire, Connecticut

Site Name:
Gas Station (actual site name confidential)

Location:
Cheshire, CT

Period of Operation:
October 1997 to March 1999

Cleanup Authority:
RCRA UST (Connecticut LUST Program)

Purpose/Significance of Application:
Use of *in situ* bioremediation to treat MTBE in groundwater

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX, TPH

- MTBE concentrations as high as 6,000 ug/L
- BTEX concentrations as high as 14,000 ug/L

Waste Source:
Leaks from an underground gasoline storage tank

Project Contact:
David Lis, IEP
Apex Environmental
58H Connecticut Avenue
South Windsor, CT 06074
Telephone: (860) 282-1700

State Contact:
Alan Davis
Connecticut Dept. of Environmental Protection
79 Elm Street
Hartford, CT 06106-5127
Telephone: (860) 424-3342

Vendor:
Brian L. Clark, P.E.
Executive Vice President
Enzyme Technologies, Inc.
5228 NE 158th Avenue
Portland, OR 97230
Telephone: (503) 254-4331 x11
Fax: (503) 254-1722
E-mail: brianc@enzymetech.com

Technology:
In Situ Bioremediation

- *In situ* bioremediation using the Enzyme-Catalyzed *In Situ* Dissolved Oxygen Treatment (DO-IT) process; patented process uses a combination of proprietary multi-enzyme complexes (proteins that are extracted from living TPH-degrading bacterial cultures), and a consortium of total petroleum hydrocarbon (TPH) degrading bacteria, with supplemental oxygen; generates a concentration of dissolved oxygen in water of approximately 40 mg/L
- Existing horizontal air sparging trench and vertical vapor extraction wells were retrofitted and used as injection points; groundwater was extracted from an existing group of wells located down-gradient from the injection points; layout provided for both treatment and hydraulic control
- Oxygen-laden water was injected on a daily basis; nutrients, including nitrogen, phosphorus, and potassium, were dissolved in the injection water, and applied "as necessary"; information was not available about the amount of amendments added, or the dates for adding amendments.

Type/Quantity of Media Treated:
Groundwater

- Depth to groundwater is less than 10 feet below ground surface (bgs)

Regulatory Requirements/Cleanup Goals:

- The cleanup criteria specified for groundwater at this site were MTBE - 70 ug/L, benzene - 1 ug/L, and TPH - 500 ug/L

Results:

- During the first 34 days of operation, MTBE concentrations in a well located within the center of the plume was reduced from approximately 6,000 ug/L to 1,600 ug/L (a 73% reduction) and from approximately 6,000 ug/L to 200 ug/L (a 97% reduction) in a downgradient well; BTEX concentrations were reduced by 93% from 14,000 ug/L to less than 1,000 ug/L
- Data available for BTEX and TPH after 12 months of operation showed a general decrease in concentrations (MTBE data were not provided)
- After 18 months of operation, the vendor reported that the cleanup criteria specified for this site for MTBE, benzene, and TPH were achieved; information about specific levels achieved was not provided

In Situ Bioremediation at Gas Station, Cheshire, Connecticut

Costs:
Information on the costs for use of *in situ* bioremediation at this site was not provided.

Description:
Releases from underground storage tanks (USTs) at an active gasoline service station located in western Connecticut resulted in contamination of groundwater at the site with MTBE and BTEX. Concentrations of MTBE and BTEX measured in groundwater at the site were 6,000 ug/L and 14,000 ug/L, respectively. The vendor estimated that 1,000 cubic yards of soil and groundwater at the site were contaminated as a result of the release. In the early 1990s, the USTs were removed and decommissioned. A groundwater extraction and treatment system and an air sparging/soil vapor extraction (SVE) system were installed to treat soil and groundwater at the site. In 1997, the groundwater treatment and air sparging/SVE systems were replaced with *in situ* bioremediation.

The DO-IT process applied at this site by retrofitting an existing horizontal air sparging trench and vertical vapor extraction wells were retrofitted as injection points for the oxygenated water, nutrients, and enzyme/bacterial consortium mixture. The vendor reported that the cleanup criteria specified for this site for MTBE, benzene, and TPH were achieved in approximately 18 months of treatment. According to the vendor, this was the first permitted *in situ* bioremediation project in the state of Connecticut. The relatively shallow depth to groundwater provided for a greater degree of contact between the oxygen, nutrients, and biological products with the contaminants of concern.

In Situ Bioremediation at Hayden Island Cleaners, Portland, Oregon*

Remediation Technology

- Hydrogen Release Compound, Regenesis, Inc.

Site Description

- This is an active Perchloroethene (PCE) drycleaning facility that has been in operation since 1975. It is located in a commercial setting adjacent to the Columbia River.

Site Hydrogeology

- Depth to Water: 6-8 feet
- Upper Surficial Aquifer: 20-40 feet of silty sand
  - Hydraulic Gradient: 0.001 ft./ft.
  - Hydraulic Conductivity: ft./day
  - Seepage Velocity: ft./day.
- Lower Regional Drinking Water Aquifer: n/a
  - Hydraulic Gradient: n/a
  - Hydraulic Conductivity: n/a
  - Seepage Velocity: n/a

Groundwater Contamination

- Contaminants Present: PCE, trichloroethene (TCE), and cis 1,2-dichloroethene (cis- DCE)
- Highest Contaminant Concentrations: 1,230 mg/l PCE, 1 mg/l TCE, and 3.4 mg/l cis 1,2-DCE.
- Deepest Contamination: Chlorinated solvents present in regional groundwater aquifer, though not attributed to site.

Remediation Scenario

- Treatment Area: 200 square feet (two "treatment" walls)- Upper Surficial Aquifer
- Quantity: 2,310 pounds of HRC
- Injection: By direct push technology at 42 locations, spaced on 10-foot centers. (Two 2 x 80 foot grid walls) at depths from 25 - 40 ft. bgs.
- Volume: (3.2 lbs./ft)/per injection point

Results

- % Mass Reduction (after 1 year, 3 months):
  - PCE - 87%
  - Substantial increase of daughter products TCE, cis-1,2-DCE

Costs

- Overall Project - $ 46,000
- HRC product - $ 14,000 ($6.00/lb)
- HRC Install $45,000
- HRC Groundwater Monitoring $20,000
- HRC Total $65,000

Lessons Learned

1. Location of site next to river complicated the hydrogeology of the site. River stage and tidal fluctuations accounted for flow reversals at the site. In addition, the timeframe of the injection occurred during the slowest groundwater transport period which required several months for HRC enhanced remediation to be noticed.

2. HRC was injected along two transects to account for groundwater flow reversals. The injections were designed to provide an engineered "treatment wall" or zone prior to off-property and surface water discharge migration.

3. A steam-cleaner is very helpful with clean-up of HRC product. Cleanup should commence the same day as injection activities. Waiting until the following day or at the end of injection event necessitated additional labor/time.

4. Analysis of acid in water sooner would have helped facilitated the amount of HRC remaining in the subsurface.

5. Regenesis offers onsite assistance and instruction during injection activities. Their guidance was very useful during the initiation of the project.

Contacts

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* This is the complete report provided by the State Coalition of Dry Cleaners (*www.drycleancoalition.org*) for this project. A separate abstract for this project is not available.

In Situ Bioremediation at Lawrence Livermore National Laboratory, California

<table>
<tr><td colspan="2">Site Name:
Not provided</td><td>Location:
Not provided</td></tr>
<tr><td colspan="2">Period of Operation:
Not provided</td><td>Cleanup Authority:
Not identified</td></tr>
<tr><td colspan="2">Purpose/Significance of Application:
Research on microbial organisms to degrade MTBE in soil and groundwater</td><td>Cleanup Type:
Bench scale</td></tr>
<tr><td colspan="2">Contaminants:
MTBE</td><td>Waste Source:
Leaking underground fuel storage tanks</td></tr>
<tr><td rowspan="2">Point of Contact:
Rolf Halden, Ph.D., P.E.
Lawrence Livermore National Laboratory (LLNL)
7000 East Ave., P. O. Box 808, L-542
Livermore, CA 94551
Telephone: (925) 422-0655
Fax: (925) 423-7998
E-mail: halden1@llnl.gov</td><td colspan="2">Technology:
Bioremediation

Research on MTBE/TBA Degraders:
• Methanotrophs Study - study of two methanotrophic microorganisms, <i>Methylosinus trichosporium OB3b</i> and <i>Methylosinus sporium</i>, grown with methane as the single carbon source.
• Long-term <i>In Situ</i> Enrichment of TBA Degraders - study attempted to isolate TBA degraders from a chemical manufacturing site where TBA degraders in the range of 67 to 460,000 degrader per gram of sediment had been reported over a 10 year period
• Cultures Using MTBE as Growth Substrate - tested the Pelorus Environmental and Biotechnology Corp. (PEL) presumed pure culture (PEL-Pg) and the PEL consortium culture (PEL-CON); derived from leaking underground fuel tank (LUFT)-sediment samples and reportedly used MTBE as the sole carbon and energy source.
• Culture Derived from Biofilter - used biomass from an experimental biofilter from the Joint Water Pollution Control plant in Whittier, California; material observed to rapidly degrade >90% MTBE after a one year adaptation period.
Palo Alto LUFT Sites Screening Study:
• Used soil (sediment) and groundwater samples from a site in Palo Alto (collected at a depth of 18-26 feet where aqueous MTBE concentrations were in the low ppm range)
• Microcosms constructed from these materials either mimicked the anaerobic conditions prevailing at the site, or contained various amendments ranging from nutrients, to oxygen, to microbial biomass
• The groundwater used to construct the microcosms was first sparged to drive off volatile contaminants and then respiked to yield an initial aqueous MTBE concentration in the microcosm of about 420 μg/L; microcosms were incubated for 3 months at 20°C and 6 rpm.</td></tr>
<tr><td colspan="2">Type/Quantity of Media Treated:
Soil and Groundwater</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
Studies were conducted to evaluate the potential for difference microbial cultures to degrade MTBE in soil and groundwater. No specific treatment goals were identified.</td></tr>
</table>

Results:
Research on MTBE/TBA Degraders:
-Methanotrophs Study - in resting cell assays, both organisms failed to degrade detectable amounts of TBA, MTBE, ethyl tert butyl ether (ETBE), diisopropyl ether (DIPE), and tert amyl methyl ether (TAME).

- Long-term *In Situ* Enrichment of TBA Degraders - no microorganisms were detected that could grow on minimal medium using TBA as the sole carbon and energy source.
- Cultures Using MTBE as Growth Substrate - during testing, the PEL-Pg culture was found to be a consortium of two different strains; neither of these two isolates nor the PEL-CON culture grew on MTBE/TBA or degraded these compounds
- Culture Derived from Biofilter - MTBE and TBA was degraded; however, microbial growth associated with MTBE depletion was extremely slow and resulted in undesirable cell clumping, potentially limiting applicability

Palo Alto LUFT Sites Screening Study:

- MTBE generally persisted under anaerobic conditions; the addition of ORC® and BioPetro did not stimulate MTBE degradation under anaerobic conditions
- MTBE was degraded completely in live, aerobic microcosms; however, the presence of additional carbon sources (sucrose contained in the BioPetro microcosms, isopropanol, and pasteurized cells) inhibited intrinsic MTBE biodegradation.

Costs:
No cost data were provided

Description:
Researchers at Lawrence Livermore National Laboratory (LLNL) conducted several studies to evaluate the potential of various microorganisms to degrade MTBE in soil and groundwater. Research studies were performed on MTBE/TBA Degraders using different microbial cultures, including several that had been observed to degrade MTBE in other settings. In addition, a study was conducted to assess the potential use of intrinsic and/or engineered *in situ* bioremediation for the restoration of MTBE-impacted soils and groundwater at leaking underground fuel tank (LUFT) sites. The study locations, all situated in Northern California, were identified by the Santa Clara Valley Water District and the San Francisco California Regional Water Quality Control Board as high risk sites, based on their proximity to public drinking water wells and/or the presence of extremely high concentrations of MTBE in shallow groundwater. The overall goal of the study was to provide general conclusions concerning the fate of MTBE at LUFT sites.

The results showed that two methanotrophic microorganisms did not transform MTBE, TBA, ETBE, DIPE, and TAME. In addition, long-term enrichment under site-specific conditions may fail to produce strains that effectively degrade TBA/MTBE. According to the researchers, careful selection of experimental media is important to identify “real” MTBE degraders, and fast-growing MTBE degraders that are needed for bioaugmentation are currently not available. Results of the Palo Alto study indicate that MTBE may biodegrade naturally at LUFT sites in some instances when conditions are favorable (e.g., aerobic conditions, no BTEX compounds present).

In Situ Bioremediation Using ORC® at an Active Service Station, Southern California

Site Name:
Service Station (actual name confidential)

Location:
Southern California

Period of Operation:
155 days in duration (specific dates were not provided)

Cleanup Authority:
State

Purpose/Significance of Application:
Use of *in situ* Bioremediation using Oxygen Release Compound (ORC®) to treat MTBE in groundwater

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX
- MTBE concentrations as high as 13,000 ug/L
- BTEX concentrations as high as 25,000 ug/L

Waste Source:
Leaks from gasoline storage tanks

Vendor:
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San Clemente, CA 92672
Telephone: (949) 366-8000
Fax: (949) 366-8090
E-mail: steve@regenesis.com

Technology:
In Situ Bioremediation using ORC®
- A total of 750 pounds of ORC® was injected through 18 direct-push bore holes located within the source area by pushing hollow rods with removable tips to a depth of 28 ft, and then pumping ORC®-slurry through the rods as they were raised from a depth of 28 ft to 18 ft.
- An additional 150 pounds of ORC® was injected through 12 direct-push bore holes located at the property boundary.
- Groundwater samples were collected from representative monitoring wells prior to injection and then approximately monthly for five months after injection

Type/Quantity of Media Treated:
Groundwater
- The direction of groundwater flow at the site is west to southwest at an average gradient of 0.0037 ft/ft and velocity of 0.067 to 0.24 ft/day
- The quality of the groundwater in the area of the site is classified as poor due to high concentrations of dissolved solids

Regulatory Requirements/Cleanup Goals:
- No information about specific treatment goals was provided

Results:
- For the first two months following the injection of ORC®, MTBE, BTEX constituents, and TPH concentrations in well MW-14 (located in the source area) decreased and the oxidation/reduction potential increased to a positive value, indicating an increase in the oxidation conditions in the subsurface
- After the second month, concentrations of MTBE, BTEX constituents, and TPH rose to pre-injection levels and the oxidation/reduction potential decreased to a negative number
- By the fifth month (day 155), concentrations of MTBE, BTEX constituents, and TPH were above pre-injection levels
- According to the vendor, possible reasons for the increases in concentrations included: 1) actual dissolved fuel hydrocarbon concentrations may have been higher than expected, exhausting the oxygen before all hydrocarbons were metabolized; 2) the elevated salinity of the groundwater may have caused the DO to be released at a rate higher than could be used by existing site microbes; and 3) fuel hydrocarbons which remained adsorbed to the soil particles in the capillary fringe may have provided a source to reintroduce hydrocarbons in the dissolved phase.

Costs:
No cost information for this application was provided.

In Situ Bioremediation Using ORC® at an Active Service Station, Southern California

Description:
The site is an active gasoline service station located on the coast of southern California, at the mouth of San Juan Creek Valley, about one-third of a mile north of the Pacific Ocean. In the early 1990's, two underground gasoline storage tanks were replaced and soil contaminated with petroleum hydrocarbons was found beneath the tank cavity and one of the gasoline dispenser islands. TPH concentrations were found in soil at levels up to 9,000 mg/kg. In groundwater, BTEX compounds were found at levels as high as 25,000 ug/L for benzene, and MTBE was found at levels as high as 13,000 ug/L. There are two dissolved-phase plumes at the site, BTEX and MTBE. In the mid-1990's, soil vapor extraction (SVE) was used at the site for approximately 13 months. While data on SVE performance was not provided, the technology did not have a long-term impact on the concentrations of dissolved-phase hydrocarbon in the saturated zone, and fuel remained adsorbed to soil within the vadose zone. ORC® was injected at the site to reduce the dissolved-phase concentrations of BTEX and MTBE and to contain the contaminant plume.

A total of 750 pounds of ORC® was injected through 18 direct-push bore holes located within the source area and sn additional 150 pounds of ORC® was injected through 12 direct-push bore holes located at the property boundary. The application of ORC® initially reduced contaminant concentrations in the groundwater for MTBE, BTEX, and TPH. However, after two months, contaminant concentrations began to rise and were above the pre-injection levels by the fifth month. Possible reasons for the increase in concentration included the presence of a continuing source of hydrocarbons and subsurface conditions that adversely affected the existing microbes at the site.

In Situ Bioremediation Using ORC® at an Active Service Station, Lake Geneva, Wisconsin

Site Name:
Service Station (actual name confidential)

Location:
Lake Geneva, Wisconsin

Period of Operation:
280 days in duration (specific dates not provided)

Cleanup Authority:
State

Purpose/Significance of Application:
Use of *in situ* Bioremediation using ORC® to treat MTBE in groundwater

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX
- MTBE concentrations as high as 800 ug/L
- BTEX concentrations as high as 14,000 ug/L

Waste Source:
Leaks from gasoline storage tanks

Vendor:
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1011 Calle Sombra
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Telephone: (949) 366-8000
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E-mail: steve@regenesis.com

Technology:
In Situ Bioremediation using Oxygen Release Compound (ORC®)
- A total of 17,000 pounds of ORC® slurry (magnesium peroxide compound) was injected into the backfill excavation using a Geoprobe® (direct push) and 37 injection points
- Two monitoring wells, located downgradient of the former UST area, were used to monitor levels of MTBE and BTEX in the groundwater

Type/Quantity of Media Treated:
Groundwater
-The groundwater flow is generally to the east northeast at a velocity of 0.2 ft/day

Regulatory Requirements/Cleanup Goals:
- No information about specific treatment goals was provided

Results:
- After nine months of operation, concentrations of MTBE in the two wells had been reduced to levels below 2 ug/L, from initial concentrations of 800 ug/L and 70 ug/L, respectively.
- During the first month of operation, MTBE concentrations in one well increased from about 800 ug/L to 1,800 ug/L, then showed a steady decline over the next eight months. MTBE concentrations in the other well declined rapidly during the first three months of operation and remained at low levels during the next five months of operation.

Costs:
No cost information for this application was provided.

Description:
Groundwater at a service station, located in Lake Geneva, Wisconsin, was found to be contaminated with high levels of MTBE and BTEX. Concentrations as high as 800 ug/L for MTBE and 14,000 ug/L for BTEX were detected in the contaminant plume. The source of the contamination was a leaking underground storage tank. Source control activities included removal of the UST and excavation of contaminated soil. Following the removal of the UST and contaminated soil, ORC® was injected into the groundwater to enhance aerobic biodegradation in the saturated zone.

The application of ORC® slurry at the Lake Geneva former UST site reduced MTBE concentrations in groundwater from initial concentrations as high as 800 ug/L to less than 2 ug/L in nine months. MTBE groundwater concentrations dropped significantly within the first three months following injection, and remained at low levels throughout the next six months. According to Regenesis, the site has been submitted to the state for closure.

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In Situ Bioremediation at South Beach Marina, Hilton Head, South Carolina

Site Name:
South Beach Marina

Location:
Hilton Head, SC

Period of Operation:
February 1999 - present (data available through September 2000)

Cleanup Authority:
RCRA UST

Purpose/Significance of Application:
Use of *in situ* bioremediation to treat MTBE in groundwater

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX, Naphthalene

Waste Source:
Leaks from an underground gasoline storage tank

State Contact:
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Hydrogeologist
South Carolina Dept. of Health and Environmental Control
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Telephone: (803) 898-4362
Fax: (803) 898-4330
E-mail:
thomadl@columb26.dhec.state.sc.us

Contractor:
John Collins
NESCO
521 Clemson Road
Columbia, SC 29229
Telephone: (803) 699-1976
Fax: (803) 699-9863

Technology:
In Situ Bioremediation
- Liquid microbial solution, manufactured by The Critter Company (TCC) and consisting of microbes (*Pseudomonas, Bacillus, and Corynebacterium*), oxygen emulsifier, surfactant, encapsulant, and nutrients was injected into the subsurface through monitoring and injection wells
- Five injections to date including: February 1999 - 150 gallons injected into 21 monitoring wells and 15 Geoprobe® injection points at pressures ranging from 5 to 20 pounds per square inch; March 1999 - 650 gallons injected into nine newly installed injection wells; December 1999 - 700 gallons injected into nine injection wells and three monitoring wells; March 2000 - 700 gallons injected into nine injection wells and four monitoring wells; and May 2000 - 700 gallons injected into nine injection wells and four monitoring wells

Type/Quantity of Media Treated:
Groundwater
- Depth to groundwater is 4.32 to 6.92 feet below ground surface (bgs)
- Average hydraulic gradient is 0.078 feet/feet with a calculated seepage velocity of 6.42 feet per year
- No confining units were identified at the site

Regulatory Requirements/Cleanup Goals:
- Site-specific target levels (SSTLs) were established by SCDHEC for MTBE, benzene, toluene, ethylbenzene, xylenes, and naphthalene, with four monitoring wells used in setting the SSTLs.
- Total SSTLs (sum of individual SSTLs for each well) - MTBE - 120 ug/L; benzene - 20 ug/L; toluene - 2,615 ug/l; ethylbenzene - 1,741ug/L; xylenes - 5,471ug/L; naphthalene - 100 ug/L

Results:
- As of September 2000, the SSTL for ethylbenzene has been met; however MTBE, benzene, toluene, xylenes, and naphthalene remain above the SSTLs
- MTBE levels decreased by 96% (from 3,310 to 146 ug/L), while benzene decreased by 83% (2,571 ug/L to 435 ug/L); toluene by 66% (24,330 ug/L to 8,300 ug/L), and naphthalene by 84% (5,377 ug/L to 853 ug/L); xylene levels decreased following the injections in February and May 1999, then increased and were above pre-operational level as of September 2000
- The system will continue to be operated until all SSTLs have been met; the contractor projects that cleanup of the site will be completed by February 2001

Costs:
- The total cost for the cleanup of this site is $63,500
- The South Carolina Petroleum Cleanup Fund awarded the contract for the cleanup at this site as a fixed-price, lump sum with no change orders; no additional information on cost breakdown was available.

In Situ Bioremediation at South Beach Marina, Hilton Head, South Carolina

Description:
South Beach Marina is a gasoline dispensing station located in Hilton Head, South Carolina. In August 1995, a release was reported from the station's underground storage tank (UST). Groundwater at the site was found to be contaminated with MTBE, BTEX, and naphthalene. Data from 1998 showed concentrations of contaminants in groundwater as high as 1,320 ug/L for MTBE, 1,250 ug/L for benzene, 21,500 ug/L for toluene, 657 ug/L for ethylbenzene, 3,140 ug/L for xylenes, and 4,720 ug/L for naphthalene. A Corrective Action Plan (CAP) was implemented in May 1999 under Subtitle I of the RCRA program. The CAP included *in situ* bioremediation.

In situ bioremediation at the site was begun in February 1999 and has included five injections of a liquid microbial solution, manufactured by The Critter Company (TCC). The solution consisted of microbes (Pseudomonas, Bacillus, and Corynebacterium), oxygen emulsifier, surfactant, encapsulant, and nutrients, and was injected into the subsurface through monitoring and injection wells in February, March, and December 1999 and in March and May 2000. As of September 2000, the SSTL for ethylbenzene has been met. While reductions in levels have been observed for for MTBE, benzene, toluene, and naphthalene, these contaminants remain above the SSTLs. Levels of xylenes have increased above pre-operational levels. The system will continue to be operated until all SSTLs have been met, with the site contractor projecting completion of the remediation by February 2001.

In Situ Bioremediation Using Butane

Site Name: Not provided	**Location:** Not provided
Period of Operation: Not provided	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Bench-scale testing of the Butane Biostimulation Technologies^{TM} process to treat MTBE in groundwater	**Cleanup Type:** Bench scale
Contaminants: MTBE	**Waste Source:** Not identified
Vendor: Felix A. Perriello, CHMM, CPSS, CPG Global BioSciences, Inc. 608 Normandy Drive Norwood, MA 02062 Telephone: (781) 762-0590 Fax: (781) 762-0590 E-mail: felix@biobutane.com	**Technology:** Bioremediation • Global BioSciences, Inc. (GBI) has patented the Butane Biostimulation Technologies^{TM} process, involving injecting butane into a contaminated area using a specially designed delivery system • In a bench-scale test, MTBE cometabolism was evaluated using Butane-utilizing BacteriaÔ suspended in 45 milliliters (ml) of sterile mineral salts medium. The bacteria consisted of groups of cells from the following genera: *Pseudomonas*, *Variovorax*, *Nocardia*, *Chryseobacterium*, *Comamonas*, and *Micrococcus*. Bacteria used for this study were isolated from gasoline-contaminated soil and groundwater. • Growth was monitored in 120 ml serum bottles under a butane, MTBE, and air mixture (approximate butane:MTBE ratio was 28:1).
	Type/Quantity of Media Treated: Soil and Groundwater
Regulatory Requirements/Cleanup Goals: Not identified	
Results: • Butane consumption rates between 1.5 and 6.0 mg/hr/L were measured for selected consortia using a gas chromatograph equipped with a photoionization detector (GC-PID) • MTBE concentrations in the headspace were reduced from as high as 10 mg/L (arbitrary concentration used in study) to sub-ppb levels within a 48-hour period, as measured using a GC-PID. Byproducts that were measured included carbon dioxide and dissolved oxygen, although concentrations were not provided in the available materials. - The vendor reported that these data demonstrated the potential for the bioremediation of MTBE using butane as a cometabolic substrate	
Costs: No cost data were provided	

In Situ Bioremediation Using Butane

Description:
GBI's Butane Biostimulation Technologies^{TM} process involves injecting butane into a contaminated area using a specially designed delivery system. According to GBI, the injection system is safe, code compliant, and requires little maintenance and technician oversight. GBI's approach to treating contaminated soil and groundwater relies on the ability of different bacteria to cooxidize chlorinated solvents, BTEX and MTBE, as well as a variety of other environmental pollutants, while growing at the expense of butane. Butane is the most soluble of the gaseous alkanes, having four times the solubility of methane, and more than twice that of propane. Butane injection results in a large radius of influence at injection wellheads and may be used as a barrier technology. To date, data are available only for bench-scale testing of Butane Biostimulation Technologies^{TM} for MTBE.

Results of bench-scale testing showed that MTBE concentrations in the headspace were reduced from as high as 10 mg/L to sub-ppb levels within a 48-hour period. Byproducts included carbon dioxide and dissolved oxygen. The vendor reported that these data demonstrated the potential for the bioremediation of MTBE using butane as a cometabolic substrate. GBI has begun a field demonstration using Butane Biostimulation Technologies^{TM} to remediate an MTBE plume at a Sun Oil Company facility. Preliminary data from this test site were not available at the time of this report. Five additional full-scale technology applications of Butane Biostimulation Technologies^{TM} are planned to be performed in 6 to 18 months at sites contaminated with MTBE and at sites contaminated with chlorinated solvents. No cost data were provided for this process.

In Situ Bioremediation at Port Hueneme, California

Site Name:
U.S. Navy Construction Battalion Center

Location:
Port Hueneme, California

Period of Operation:
Laboratory testing - April 1998
Pilot testing - June to August 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Laboratory and field testing of *in situ* bioremediation using MC-100 to treat MTBE in groundwater

Cleanup Type:
Laboratory and Pilot-scale

Contaminants:
MTBE and TBA
- MTBE concentrations ranged from 2,000-8,000 ug/L; plume 4,000 feet (ft) long and 400 ft wide
- TBA concentrations ranged from 50-250 ug/L

Waste Source:
Leaks from gasoline storage tanks

Technology Provider:
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Environmental Technology
Westhollow Technology Center
3333 S. Highway 6 (P.O. Box 1380)
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Technology Researcher:
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Fax: (480) 965-0557
E-mail: paul.c.johnson@asu.edu

Technology:
In Situ Bioremediation
- Laboratory testing of microbial culture MC-100 (previously referred to as BC-4) under anoxic conditions and oxygenated conditions in soils augmented with specific ether degraders
- Field test using a MC-100 microbial consortium grown with MTBE as the sole carbon source; specific MTBE removal rate of 20-30 mg/gm cells/hr; injected into test plots located within the MTBE plume; test plots were 20 ft wide and 40 ft long
- On-site oxygen generating system (Air-Aep AS-80 pressure swing adsorption system); intermittent oxygen sparging using a total of 1700L gas delivered to each plot from 4-8 times/day (started six weeks prior to MC-100 seeding to increase levels of DO in groundwater)
- Monitoring wells were screened over 5-ft intervals - 10-15 ft bgs for shallow wells; 15-20 ft bgs for deep wells

Type/Quantity of Media Treated:
Groundwater
- Water table is approximately 13 ft below ground surface (bgs)
- Aquifer sediments consist of silty loam and fine-medium sandy soils

Regulatory Requirements/Cleanup Goals:
- Field experiments were designed to implant high densities of MC-100 in an oxygenated biobarrier and to compare the results with those for an oxygenated zone and a control zone
- Cleanup goals for MTBE and TBA are 5 and 10-15 ug/L, respectively, as stated in State of California MCL directives.

In Situ Bioremediation at Port Hueneme, California

Results:

Laboratory results

- Addition of MC-100 (50 mg cells/L groundwater) reduced MTBE to non-detectable levels within two weeks
- Microcosms prepared with soil and oxygenated groundwater from the Port Hueneme site containing gasoline (700 mg/L) also degraded MTBE (70-80 mg/L) and BTEX (45 mg/L) to non-detect levels in 16 weeks when seeded with MC-100 at 50 and 250 mg cells/kg soil.

Pilot-scale results

- DO levels in target treatment zones increased from <1 mg/L to >10 mg/L - >20 mg/L
- Oxygen plus MC-100 plot reduced concentrations of MTBE from 1,000 ug/L to < 1 ug/L and TBA from 50-250 ug/L to <10 ug/L; oxygen-only plot reduced MTBE concentrations to 10 ug/L (where DO was about 20 mg/L), but TBA was not degraded; in the control plot, the concentration of MTBE remained at approximately 1 mg/L; no TBA data were provided

Costs:

- Full-scale costs for *in situ* bioremediation of MTBE using the oxygenated biobarrier was projected by the technology provider to be about $150,000, depending on site-specific conditions.

Description:

From 1984-1985, several thousand gallons of leaded gasoline containing MTBE were released from storage tanks at the Naval exchange (NEX) gasoline station of the naval base at Port Hueneme, California, resulting in MTBE and BTEX plumes. Laboratory and field experiments of *in situ* bioremediation using addition of oxygen and the MC-100 culture were conducted at Port Hueneme. The MC-100 culture, which is part of the patented “BioRemedy” process developed at the Westhollow Technology Center, is marketed by Shell Global Solutions. Equilon Enterprises LLC designs and implements the process, which is expected to be commercially available in early 2000.

Laboratory testing indicated that MTBE and BTEX could be degraded with oxygen in soils augmented with MC-100. For the field tests, the DO levels in the aquifer were increased from <1 mg/L to between 10 and 20 mg/L, prior to the addition of MC-100. Results showed that the oxygen plus MC-100 reduced MTBE and TBA concentrations to < 1 ug/L and < 10 ug/L, respectively. The *in situ* bioremediation of MTBE using the oxygenated biobarrier was estimated by the technology provider to cost about $150,000 for a full-scale application, depending on site-specific conditions. According to the technology provider, inoculation of subsoils with specific MTBE-degraders and maintaining adequate oxygenation of the aquifer will enhance MTBE biodegradation *in situ* and control the MTBE plume mass from reaching potential downstream receptors. Additional benefits of inoculated barriers over oxygen-only sparged aquifers is that MTBE-degraders may not be present in many aquifers or are present in insufficient numbers to sustain MTBE degradation in plumes over long periods.

In Situ Bioremediation at Vandenberg Air Force Base, Lompoc, California

Site Name:
Vandenberg Air Force Base

Location:
Lompoc, California

Period of Operation:
1999 to ongoing (data available through December 1999)

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Use of *in situ* bioremediation to treat MTBE in groundwater

Cleanup Type:
Field demonstration

Contaminants:
MTBE
- MTBE plume extends about 1,700 feet downgradient

Waste Source:
Leaks from gasoline storage tanks

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Site Representative:
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Technology:
In Situ Bioremediation
- Field demonstration conducted within MTBE plume, where MTBE was identified as the primary contaminant
- Three pilot tests were performed - release wells, release panel, and emplaced MTBE degraders (strain PM1, permeable trench); multi-level monitoring wells (screened at varying depths) were used for each test
- Release Wells - two, 8-inch diameter wells (RW1 and RW2) screened to 8 feet below ground surface (bgs); each well was equipped with an oxygen emitter
- Release Panel - consists of three layers of prefabricated stripdrain material, each layer 6 feet by 6 feet and about 1 inch thick; continuous lengths of 1/4 inch tubing woven around the internal supports; panel placed in a trench and backfilled with native soil and pea gravel. During operation, oxygen was cycled on and off to test the system.
- Emplaced MTBE Degraders - test area consisted of a section of pea gravel (1.5 ft wide, 1.5 ft long, and 12 ft deep); PM1 was injected in slurry form using three injection wells; solution was extracted from a well located downgradient
- Sulfur hexafluoride (SF_6) was used as a tracer in each test

Type/Quantity of Media Treated:
Groundwater

Regulatory Requirements/Cleanup Goals:
- Goal of field demonstrations is to study possible methods for stimulating aerobic *in situ* bioremediation of MTBE by increasing the concentration of dissolved oxygen (DO)
- No information about specific treatment goals was provided

Results:
- Release Wells - No MTBE data were available for this pilot test. After 140 days of operation, DO concentrations were 2.5 mg/L in downgradient wells and a gradual buildup of SF_6 in the release wells was observed. According to the researchers, this indicates that the emitters are working as expected.
- Release Panel - During the first "on" cycle (August 1999) DO concentrations were as high as 23 ug/L and MTBE concentrations were reduced from 417 ug/L to below the detection limit. Data from the end of the first "off" cycle (December 1, 1999) showed that once the oxygen supply was turned off, the DO concentrations decreased to low levels (1.2 ug/L), and MTBE concentrations increased to 427 ug/L. After the oxygen was turned "on" (December 14, 1999), MTBE concentrations began to decrease from 427 ug/L to 20 ug/L (as of December 29, 1999)
- Emplaced MTBE degraders - No performance data were available at the time of this report

In Situ Bioremediation at Vandenberg Air Force Base, Lompoc, California

Costs:
Efforts are underway to develop projected costs for full-scale systems; however, no cost information was available at the time of this report.

Description:
Site 60 at Vandenberg Air Force Base (AFB) is the location of an abandoned service station. Leaks from gasoline tanks resulted in contamination of the groundwater with MTBE, BTEX, and other petroleum hydrocarbons. The MTBE plume extends approximately 1,700 feet downgradient from the source area, and the smaller BTEX/TPH plume, located within the MTBE plume, extends approximately 100 feet downgradient of the source area. A research project to study *in situ* bioremediation of MTBE has been underway at Vandenberg AFB since 1998. As part of this project, Site 60 is being used to study possible methods for stimulating aerobic *in situ* biodegradation of MTBE using native and non-native microbes. To achieve aerobic conditions in an otherwise anaerobic plume, researchers are studying the use of diffusive emitters to introduce oxygen into the subsurface.

Three pilot tests are underway at Site 60 to test *in situ* bioremediation of MTBE using release wells, a release panel, and emplaced MTBE degraders. Multi-level monitoring wells (screened at varying depths) are being used to monitor each of the pilot tests. For the pilot test of the release wells, no MTBE concentration data were available. However, DO concentrations in groundwater increased to 2.5 mg/L (after 140 days of operation). According to the researchers, these results indicate that the emitters are working as expected. For the pilot test of the release panel, data show that MTBE concentrations decrease when oxygen is provided to the groundwater ("on" cycle) and that MTBE levels increase when the oxygen source is discontinued ("off" cycle). According to the researchers, these data suggest that degradation of MTBE is dependent on oxygen release in the groundwater and also that treatment may easily be reestablished after there has been an interruption in the supply of oxygen to the groundwater. At the time of this report, performance data were not available for the emplaced MTBE degrader pilot test. The pilot tests are continuing at Vandenberg Site 60, with the most recent work focusing on the emplaced MTBE degrader pilot test. Additional investigations are underway to identify the MTBE-degrading microbes and to better understand enhanced aerobic intrinsic bioremediation of MTBE.

Bioslurping of LNAPL at Multiple Air Force Sites

Site Name: Multiple Air Force Sites (18 total; refer to case study for names and locations of each site)	**Location:** Multiple locations throughout U.S.
Period of Operation: • Periods of operation were not provided for each site	**Cleanup Authority:** Not provided
Purpose/Significance of Application: Field demonstrations of bioslurping of LNAPL at multiple Air Force sites	**Cleanup Type:** Field Demonstration
Contaminants: Light Non-aqueous Phase Liquids (LNAPL); Petroleum Hydrocarbons • LNAPL thickness ranged from 0.12 ft to 3.89 ft; for the 18 sites, 9 had thickness as less than 1 ft, 3 from 1 - 2 ft, and 6 with more than 2 ft • Fuel types consisted of No. 2 fuel oil, gasoline, jet fuel, aviation gasoline, and JP-4; 10 of the 18 sites had JP-4	**Waste Source:** Not provided
Technical Contact: Battelle 505 King Avenue Columbus, OH 43201 **Management Contact:** Jeff Cornell Air Force Center for Environmental Excellence Technology Transfer Division Brooks AFB, TX 78235 E-mail: jeff.cornell@hqafcee.brooks.af.mil	**Technology:** Bioslurping • Field demonstration of bioslurping applied vacuum in an extraction well to recover LNAPL and induce airflow through the unsaturated zone • Equipment included a tube placed in a well with the tip near the water table level, and operated with a vacuum of up to 20 inches of mercury **Type/Quantity of Media Treated:** LNAPL • Depths to groundwater ranged from 8 to 37 ft bgs • Pressure radius of influence ranged from 12 to 250 ft • Hydraulic conductivity ranged from 0.23 to 23.78 ft/day

Regulatory Requirements/Cleanup Goals:

- Goals of the demonstration included recovering the "maximum quantity" of LNAPL
- Bioslurping was evaluated relative to the performance of skimming and drawdown pumping for the 18 sites in the study

Results:

- The LNAPL recovery rates for bioslurping ranged from <0.1 to 64.2 gal/day, compared to skimming and drawdown pumping at 3.1 gal/day and 4.5 gal/day, respectively
- The groundwater removal rates for bioslurping ranged from <30 to 4,600 gal/day, compared to drawdown pumping at 1,640 gal/day and <29 gal/day for skimming
- The off-gas flow rate from the bioslurper systems was 65 scfm (9 wells, each producing 7.2 scfm), while the skimming and drawdown systems had negligible off-gas flows

Costs:

- Projected costs for a bioslurping system was capital cost of $92,507 and monthly operating cost of $12,342; the overall cost for capital and 6 months of operation was less for the bioslurper than for either the skimming or drawdown systems identified in the study
- Projected costs for a skimming system was capital cost of $110,328 and monthly operating cost of $11,120; projected costs for a single pump drawdown system was capital cost of $131,172 and monthly operating cost of $11,268
- A calculated unit cost for bioslurping was $56/gal LNAPL recovered, which was less than the unit cost for skimming ($339/gal) or drawdown ($260-312/gal)

Bioslurping of LNAPL at Multiple Air Force Sites

Description:
The Air Force Center for Environmental Excellence (AFCEE) conducted an engineering evaluation and cost analysis of vacuum enhanced free product recovery (bioslurping), including a comparison of bioslurping with other free product recovery techniques skimming and drawdown pumping. Field demonstrations of bioslurping were conducted at 18 Air Force sites throughout the country.

The sites included in the evaluation showed that bioslurping recovered LNAPL at a higher rate than either skimming or drawdown pumping. The bioslurping and drawdown systems removed comparable amounts of water, while the skimming system removed negligible water. The bioslurper had measurable off-gas flow rates, while the other two systems had negligible flow rates. An analysis of costs showed that the overall cost for capital and 6 months of operation was less for the bioslurper than for either the skimming or drawdown systems identified in the study.

Biosparging of Contaminated Groundwater at the T-Dock Site, South Prudence Bay Island Park, Rhode Island

Site Name:
T-Dock Site, South Prudence Bay Island Park, Rhode Island

Location:
Portsmouth, Rhode Island

Period of Operation:
Pilot Test - October to January 1997
Full-scale Operation - February 1998 to February 2000

Cleanup Authority:
State (RIDEM)

Regulatory Contacts:
Matthew DeStefano
RIDEM
235 Promenade St.
Providence, RI 02908

Purpose/Significance of Application:
The application treated BTEX-contaminated groundwater in-situ at a relatively remote site without collecting or discharging treated water.

Cleanup Type:
Full-scale Remedial Action

Contaminants:
Organic Compounds (BTEX)Maximum detected concentrations were:
- Benzene at 2,050 ug/L
- Toluene at 7,830 ug/L
- Ethylbenzene at 3,470 ug/L
- Xylene at 11,000 ug/L

Waste Source:
One gasoline UST and a fuel distribution system were operated at the site between 1940 and 1985. It is assumed that periodic leaks and spills occurred during this span.

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Technology:
Biosparging
- A pilot test was performed at the site in 1997 and 1998. Results indicated that biosparging would be an effective technology to remediate the site, and that addition of SVE would not significantly enhance the performance of the system.
- The biosparging system was installed in 1997 and included 22 sparge wells. Wells were installed at depths ranging from 15 to 26 feet bgs, and well screens were installed in the bottom two feet of each well.
- Atmospheric air was delivered to the network of sparge wells via an air compressor, a blower and a distribution manifold. Air flow rates were adjusted between 0.2 to 9.5 cfm as necessary.
- Groundwater concentrations were monitored in thirteen wells installed at the site.

Type/Quantity of Media Treated:
- The lateral extent of the groundwater plume at the site was estimated to be 35,000 SF
- The depth to groundwater at the site is typically 10 to 12 ft bgs, but decreases to 4 to 6 ft bgs near Narragansett Bay.

Regulatory Requirements/Cleanup Goals:
Remedial goals for BTEX compounds in groundwater were:
- Benzene below 5 ug/L, Toluene below 1,000 ug/L, Ethylbenzene below 700 ug/L and Xylene below 10,000 ug/L.
- The system was required to meet RIDEM air emission requirements for volatile organic compounds.

Results:
- Monitoring wells at the site were sampled quarterly from late 1997 through 2000. Results indicate that BTEX compounds in the groundwater have been treated to acceptable concentrations, with the exception of benzene in one well. The system has been shut down, and the site is currently in the closure process.· RIDEM air emission requirements were met throughout operation of the treatment system.

Biosparging of Contaminated Groundwater at the T-Dock Site, South Prudence Bay Island Park, Rhode Island

Costs:

- The total cost for this project was $280,946.

Description:

South Prudence Bay Island Park is located in Portsmouth, Rhode Island and is currently used mainly for public recreation. The T-Dock site is located on a two-acre parcel at the southern edge of the park, and is directly adjacent to Narragansett Bay. From the 1940s until 1985, fuel storage and distribution operations were conducted at the T-Dock site. In 1985 and 1992, actions were taken to remove one 10,000-gallon gasoline UST and sections of the fuel distribution pipeline at the site. Investigations conducted at the site in 1996 and 1997 indicated that soil and groundwater contamination was present in the area of the former UST and pipeline. Contaminants of concern at the site included mainly BTEX compounds. Contaminated soil was excavated at the site under a separate project performed during 1997.

In 1996 and 1997 a pilot tests were conducted in a small section of the T-Dock site. Testing included installation of one sparge well, one SVE well and six groundwater monitoring wells. The first test was performed to evaluate the expected performance of a combination of SVE and sparging. After the first test indicated that the SVE well had a limited area of influence, a second test was conducted to determine if a low-flow sparging system without SVE could be operated at the site to treat BTEX in groundwater while not exceeding RIDEM air emission standards. It was determined that a system operated with pulsed air injection at a rate of 1 cfm for twenty minutes out of each hour, would meet the requirements of the project.

The biosparging system was constructed in 1997 and 1998, and included a total of 22 sparge wells and thirteen groundwater monitoring wells. Ten of the thirteen monitoring wells were five nests of two wells each, one screened at a shallow depth and one screened deeper. Atmospheric air was delivered to the wells via an air compressor, a blower and a distribution manifold. After it was determined that air emissions standards would not be violated by increasing flow to the sparging system, air flow rates were modified as necessary to address areas of the site with higher contaminant concentrations. Air flow rates to the system were varied from 0.2 to 9.5 cfm during the project. The full-scale system was operated from February 1998 through February 2000. Quarterly sampling results indicated that BTEX compounds in groundwater had been treated to the remediation goals, with the exception of one well, which still contained benzene at a concentration above the goal. The system was shut down in February 2000 and the site is currently in the closure process. Treatment was completed in April 1999.

In Situ Chemical Oxidation at Butler Cleaners, Jacksonville, Florida*

Remediation Technology

- In-Situ Chemical Oxidation - Potassium Permanganate ($KMnO_4$)

Site Description

- This is an active PCE drycleaning site that has been in operation since 1972. The adjacent property was occupied by a gasoline station from the 1920s to the 1950s. Three USTs were removed from this site in 1992. The site is located in a residential/commercial setting.

Site Hydrogeology

- Depth to Water: 6 ft below land surface (bls)
- Unconfined Aquifer
- Lithology:
  - Surface - 28 ft bls: very fine - fine-grained sand
  - 28 - 34 ft bls: sandy clay
- Hydraulic Gradient: 0.0036 ft/ft
- Hydraulic Conductivity: 8.7 ft/day
- Seepage Velocity: 0.1 ft/day

Groundwater Contamination

- Contaminants Present: PCE, TCE, cis 1,2-DCE, trans 1,2-DCE, vinyl chloride, toluene, ethylbenzene, xylenes, naphthalene
- Highest Contaminant Concentrations: 17,000 μg/l PCE, 830 μg/l TCE, 120 μg/l cis 1,2-DCE, 1170 μg/l vinyl chloride
- Deepest Groundwater Contamination: 27 ft bls
- Contaminant Plume Size: delineation not yet completed

Remediation Scenario

- Treatment Area: approximately 10 ft x 40 ft to a depth of 30 ft
- Quantity/Concentration: 3 initial injection events of 5,000 gallons at a concentration of 7.7 g/L $KMnO_4$ (Carus Free Flowing grade) per injection event.
- Injection: 9 well clusters with 5 1-inch diameter monitoring/injection wells screened at 5-10 ft, 10-15 ft, 15-20 ft, 20-25 ft, and 25-30 ft depth intervals. Two clusters initially utilized as injection wells with other wells converted to injection wells based upon KmnO4 and contaminant distribution. Periodic injections are ongoing.

Results

- Post-pilot test monitoring indicates that, following initial injection of $KMnO_4$, contaminant concentrations decreased in areas of $KMnO_4$ distribution. However, periodic monitoring indicates that rebound of elevated PCE concentrations is occurring upon reduction of $KMnO_4$ concentrations within the formation. Rebound of PCE concentrations is likely due to the existence of residual DNAPL PCE that continues to act as an ongoing source of dissolved phase PCE contamination.

Costs

- Approximately $230,000 for design and implementation of the pilot test system and approximately $30,000 per event for quarterly monitoring and $KMnO_4$ injection (not including reporting costs).

Lessons Learned

1. $KMnO_4$ is effective for the oxidation of dissolved phase PCE contamination

2. Effective remediation of chlorinated solvent contamination using $KMnO_4$ may be confounded by the presence of DNAPL contamination due to mass transfer limitations of contaminant mass from the DNAPL to dissolved phase. Determination of the presence of residual DNAPL PCE is integral to the successful application of in-situ chemical oxidation technologies.

In Situ Chemical Oxidation at Butler Cleaners, Jacksonville, Florida*

Contacts

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LFR Levine-Fricke: Kevin Warner, P.E. (850) 422-2555

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* This is the complete report provided by the State Coalition of Dry Cleaners (*www.drycleancoalition.org*) for this project. A separate abstract for this project is not available.

In Situ Chemical Oxidation Using Fenton's Reagent at Naval Air Station Pensacola, Florida

Site Name:
Naval Air Station (NAS) Pensacola

Location:
Pensacola, FL

Period of Operation:
- 11/98 - 5/99 (for oxidation)

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
- Maximum concentrations - 3,600 ug/L for TCE, 520 ug/L for DCE, and 63 ug/L for VC

Waste Source:
Unlined sludge drying beds and surge pond

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Technology:
In situ Chemical Oxidation Using Fenton's Reagent
- *In situ* chemical oxidation using Fenton's Reagent involved pressurized injection of concentrated hydrogen peroxide and ferrous iron catalyst to oxidize organic compounds in groundwater
- A two-phase treatment was performed - in the first phase, 6 injectors were installed in the former sludge drying bed from 11 - 31 ft bgs, and 8 injectors were installed at 35 - 40 ft bgs down-gradient of the bed; a total of 4,089 gallons of 50% hydrogen peroxide and a similar volume of ferrous iron catalyst were injected over 5 days in December 1998
- In the second phase, 6,038 gallons of 50% hydrogen peroxide and a similar volume of catalyst, along with phosphoric acid, were injected over 6 days in May 1999
- A pump and treat system had been ongoing at the site since February 1987; in 1995, a review of available data showed that contamination was limited to around monitoring well GM-66, at an intermediate depth, and the number of recovery wells was reduced from 7 to 3, focused in the area near GM-66; as of 2000, the Florida DEP was allowing the pump and treat system to be discontinued and a Monitored Natural Attenuation (MNA) remedy to be used for the site

Type/Quantity of Media Treated:
Groundwater
- Geology characterized as relatively homogeneous fine to medium grained; a clay layer is located at 40 - 60 ft bgs
- Depth to groundwater is generally less than 5 ft, with a flow direction of generally east

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

Results:
- The groundwater monitoring network for the site consisted of 8 point-of-compliance wells, 10 assessment wells, and 1 background well
- The results from the first phase of treatment showed that an 81% reduction in concentrations of chlorinated solvents was achieved in GM-66, and that there was rebound in other wells
- The results from the second phase of treatment showed reduction in concentrations of chlorinated solvents, including the wells that had rebound after Phase 1, and that there had been substantial source reduction

In Situ Chemical Oxidation Using Fenton's Reagent at Naval Air Station Pensacola, Florida

Costs:

- The cost for two phases of *in situ* chemical oxidation and subsequent MNA was \$250,000 for treatment and \$100,000 per year for monitoring; the total cost of this approach was projected as \$750,000 over a five year period
- The pump and treat system had a cost of \$70,000 per year for operation and \$100,000 per year for monitoring; the total cost of the pump and treat remedy was projected to be \$3.4 million over a 20 year period
- The use of *in situ* chemical oxidation was projected to save several million dollars compared with the continued use of pump and treat

Description:

Naval Air Station (NAS) Pensacola is a 5,800-acre naval facility located in the western portion of the Florida panhandle. The former Industrial Wastewater Treatment Plant (IWWTP) at the site treated wastewater from operations such as painting and electroplating, as well as organic solvents and acids, and included an unlined sludge drying bed and surge pond. *In situ* chemical oxidation using Fenton's Reagent 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.

In situ oxidation was conducted in two phases, and included a total of 10,127 gallons of hydrogen peroxide and similar volumes of reagents injected under pressure at a depth of 10-40 ft bgs. Over the two phases, the concentration of TCE was reduced substantially. Elevated concentrations of ferrous iron in the groundwater 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.

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:
- February 1999 (for oxidation)

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
- Maximum concentrations - 8,500 ug/L for PCE, 550 ug/L for TCE, and 24 ug/L for cis-1,2-DCE

Waste Source:
Leaks from a landfill

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Technology:
In situ Chemical Oxidation Using Fenton's Reagent
- *In situ* chemical oxidation using Fenton's Reagent involved pressurized injection of concentrated hydrogen peroxide and ferrous iron catalyst to oxidize organic compounds in groundwater
- A two-phase treatment was performed using 23 injectors distributed in two vertical levels; Phase 1 was in the central portion of the plume and Phase 2 was in down-gradient areas
- A pump and treat system had been ongoing at the site since March 1994; as of July 1998, five recovery wells were operating at a combined flow rate of 55 gpm and a UV light system was added to replace a diffused aeration tank for treatment of extracted groundwater; the system was shut off in April 1999

Type/Quantity of Media Treated:
Groundwater
- Geology characterized as fine sands interbedded with silty and/or clayey fine sands and some medium sands
- Depth to groundwater is 6 ft, with a flow direction of generally northwest
- An unconfined surficial aquifer is approximately 90 ft thick, and has a hydraulic conductivity of 30 ft/day

Regulatory Requirements/Cleanup Goals:
- A cleanup objective for total VOCs in the source area was identified as 100 ug/L

Results:
- The concentrations of total VOCs were reduced to below cleanup objectives in the central portion and down-gradient areas of the plume after the two phases of treatment
- An additional source of contamination was identified to the north of the treated area; a third phase of treatment using *in situ* chemical oxidation was planned to address sources of contamination both up- and down-gradient from the previous target areas

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

Costs:

- The cost for the first two phases of *in situ* chemical oxidation and UV oxidation treatment was $1,050,000, including $900,000 for implementation, $65,000 for operations and maintenance, $40,000 for monitoring, and $15,000 for reporting
- Phase 3 was estimated to cost $282,000
- The pump and treat system had an initial capital cost of $1.5 million, with $400,000 expended each year for operations and maintenance ($12 million total projected cost)
- The use of *in situ* chemical oxidation was projected to save several million dollars compared with the continued use of pump and treat

Description:

Naval Submarine Base (NSB) Kings Bay is a 16,000 acre facility in Camden County, GA. 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 and DCE. In 1994, a groundwater pump and treat system began operation. This system reduced concentrations of chlorinated solvents, however it was projected that it would require at least 50 years of operation to meet cleanup goals. The Navy proposed use of *in situ* chemical oxidation using Fenton's Reagent to reduce groundwater contaminant concentrations, followed by natural attenuation to address residual contamination.

The *in situ* oxidation remediation was performed in two phases, addressing the central portion and down-gradient areas of the plume. The concentrations of total VOCs were reduced to below cleanup objectives in these two areas of the plume. However, an additional source of contamination was identified to the north of the treated area, and a third phase of treatment using *in situ* chemical oxidation was planned. The cost for the first two phases of treatment was $1,050,000, with Phase 3 estimated to cost $282,000.

In Situ Flushing at Camp Lejeune Marine Corps Base, Building 25, Camp Lejeune, North Carolina*

Remediation Technology

- Surfactant-Enhanced Aquifer Remediation (SEAR) with surfactant recycling and Partitioning Interwell Tracer Testing (PITT) for technology evaluation and site characterization

Site Description

- Active perchloroethylene (PCE) drycleaning facility that has been in operation since the 1940s. The drycleaner used petroleum drycleaning solvent (Varsol™) until the 1970s when it was replaced by PCE. The facility is located in the industrial portion of the Base.

Site Hydrogeology

- Depth to Water: 10 -16 ft below land surface (bls)
- Upper Surficial Aquifer: 20-60 ft of very fine-grained quartz sand with lenses and discontinuous layers of clay, silt, and peat.
  Hydraulic Gradient: 0.02 ft/ft
  Hydraulic Conductivity: 1.4 ft/day
  Seepage Velocity: 0.14 ft/day
- 0 - 14 ft of clay
- Lower Surficial Aquifer: 0-30 ft of fine-grained quartz sand with varying amounts of silt. When clay layer is absent, Upper and Lower Surficial Aquifer are hydraulically one unit.
  Hydraulic Gradient: 0.003 ft/ft
  Hydraulic Conductivity: 65 ft/day
  Seepage Velocity: 1 ft/day
- Upper Castle Hayne Aquifer: Greater than 50 ft of fine-grained quartz sand and silt with shell fragments. This is a drinking-water aquifer for the Base with most production from limestone beds not intersected by the monitoring wells at the site.
  Hydraulic Gradient: 0.0005 ft/ft
  Hydraulic Conductivity: 5.1 ft/day
  Seepage Velocity: 0.013 ft/day

Groundwater Contamination

- Contaminants Present: PCE, TCE, cis 1,2-DCE, trans 1,2-DCE, vinyl chloride, Varsol™
- Highest Contaminant Concentrations: 170,000 µg/l PCE (presence of free-phase DNAPL), 3,030 µg/l TCE, 3,725 µg/l cis 1,2-DCE, 38 µg/l trans 1,2-DCE, 4 µg/l vinyl chloride, 7,100 µg/l Varsol™
- Deepest Contamination: 85 ft bls
- Plume Size: 1,500 ft long by up to 500 ft wide (as defined by North Carolina groundwater standards)

Remediation Scenario

- Treatment Area: 20 ft x 30 ft to a maximum depth of 20 ft
- Quantity Injected: SEAR - 9,718 lb. Custom surfactant (Alfoterra 145-4-PO sulfate™), 38,637 lb isopropanol and 427 lb calcium chloride. 19% (1,800 lb) of the total surfactant injected was recycled.
- PITT: 4,800 and 4,200 gal. Water containing partition tracers (alcohols) were injected into the well field before and after the SEAR, respectively. Tracer tests required about 40 days each.

Results

- % Mass Reduction: DNAPL - 72% (74 to 88 gal DNAPL removed from test zone. 23 to 29 gal remain.
- Tracer Test Results: Pre-SEAR PITT did not sweep low permeability zone. Therefore, percent DNAPL removed (above) represents DNAPL removed from permeable zones only. Post-SEAR PITT unusable.

In Situ Flushing at Camp Lejeune Marine Corps Base, Building 25, Camp Lejeune, North Carolina*

Costs

- Unknown: Several crews onsite from March 15 to August 15, 1999. High-cost surfactant used. Technologies require a large number of sample analyses, laboratory bench test, and considerable computer simulation.

Lessons Learned

1. SEAR and PITT technologies are ineffective for sediments with permeability of less than 1.4 ft/day.

2. At this test, permeability reduction associated with a downward-fining depositional sequence kept the tracer and surfactants from reaching all of the DNAPL. The nature and impact of geologic contacts and/or transition zones needs to be evaluated before selecting technology.

3. An estimated 92 to 96% of the DNAPL swept by the surfactant flood was removed; however, the surfactant flood did not sweep a significant portion of the DNAPL.

4. There is no evidence of aquifer plugging as a result of surfactant injection.

5. Surfactant apparently biodegraded during the SEAR. Biodegradation was a result of the aquifer conditions (sulfate reducing) and the time required moving surfactant through low permeability sediments. The impact of surfactant biodegradation should be considered before applying these technologies.

6. The results of the post-SEAR PITT test were unusable apparently because surfactant degradation products sorbed on the sediment, then reacted with the tracer during the PITT.

7. The SEAR did not reduce Varsol™ contamination. Underground Injection Control regulators were told that there would be a 90% overall reduction in Varsol™. This requirement was necessary for regulatory approval of recycled surfactant re-injection.

8. Detailed borehole data (geotechnical and geologic) are needed to evaluate technologies that rely on aquifer parameters to be effective. Relying on pump and/or tracer tests without an adequate geologic model can lead to erroneous interpretations.

9. Expensive, custom-made surfactant was selected to test recycling. New surfactant had to be mixed with recycled surfactant before it could be injected. The cost-effectiveness of using recycled surfactant was not shown.

Contacts

North Carolina Division of Waste Management: Dave Lown (919) 733-2801
Camp Lejeune Installation Restoration Program: Rick Raines (910) 451-9461

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* This is the complete report provided by the State Coalition of Dry Cleaners (*www.drycleancoalition.org*) for this project. A separate abstract for this project is not available.

Mobilization, Extraction, and Removal of Radionuclides at the Fernald Environmental Management Project, Cincinnati, Ohio

Site Name:
Fernald Environmental Management Project (FEMP)

Location:
Cincinnati, Ohio

Period of Operation:
September 1998 to September 1999

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Field demonstration of *in situ* flushing as an enhancement to pump and treat technology

Cleanup Type:
Field demonstration

Contaminants:
Heavy Metals
- Uranium concentrations as high as 490 ug/L

Waste Source:
Nuclear weapons production operations

Technical Contacts:
Rob Janke
DOE-FEMP
(513) 648-3124

Dave Brettschneider
Fluor Fernald
(513) 648-5814

Terrall Putnam
Fluor Fernald
(513) 648-6363
Terrall.Putnam@fernald.gov

Management Contact:
Lynton Yarbrough
SCFA Manager
DOE Albuquerque
(505) 845-5520

Technology:
In Situ Flushing
- Referred to as Mobilization, Extraction, and Removal of Radionuclides (MERR) technology
- The demonstration used 15 extraction wells and 5 injection wells
- Groundwater was extracted, treated above-ground to remove uranium (treatment not identified), and re-injected at a rate of 1,000 gpm (5 wells at 200 gals/well)

Type/Quantity of Media Treated:
Groundwater
- The Greater Miami Aquifer is an unconfined, anisotopic, heterogeneous buried valley sand-and-gravel aquifer, ranging up to 200 ft in thickness near the FEMP
- A thin veneer of younger glacial-till deposits (mostly clay) overlay the sand and gravel unit, which in turn overlays bedrock

Regulatory Requirements/Cleanup Goals:
- Ohio's re-injection guidelines were used as a design criterion for the re-injection system, with re-injected groundwater required to meet a final remediation level (FRL) of 20 ug/L of total uranium
- The overall goal of the demonstration was to assess the performance and cost of a re-injection system as an enhancement to the existing pump and treat system
- In addition, the demonstration was used to determine if the re-injection system would maintain capture of the 20 ug/L uranium plume

Results:
- Approximately 455 million gallons of treated groundwater were re-injected
- The uranium plume (at 20 ug/L) was contained (horizontal and vertical migration)
- The system flushed contamination south of the injection wells, but not between the injection wells

Costs:
- Information was not provided about the cost of the demonstration
- Use of re-injection was predicted by DOE to save $14.3 million and reduce the remediation by seven years, compared with continued use of pump and treat

Mobilization, Extraction, and Removal of Radionuclides at the Fernald Environmental Management Project, Cincinnati, Ohio

Description:
The Fernald Environmental Management Project (FEMP) has been used for nuclear weapons production. Approximately 220 acres of the Great Miami Aquifer at this site are contaminated with uranium at concentrations greater than 20 ug/L. A Record of Decision (ROD) for O.U. 5 required use of pump and treat for aquifer remediation. Modeling results showed that a pump and treat remedy would take approximately 27 years to restore the aquifer. As a possible enhancement to the pump and treat system, an *in situ* groundwater flushing system was tested, referred to as the Mobilization, Extraction, and Removal of Radionuclides (MERR) system.

The MERR system was operated for one year along the southern property boundary, using 15 extraction and 5 injection wells. After removing uranium above-ground, the system re-injected 1,000 gpm of treated groundwater. Results from the demonstration showed that the system flushed contaminants from south of the injection wells, but not between the wells, that capture of the uranium plume was maintained, and that the plume was not pushed into deeper regions of the aquifer. DOE predicted that by re-injection $14.3 million would be saved and the time for remediation would be reduced by seven years, compared with continued use of pump and treat.

In Situ Flushing at Former Sages Dry Cleaners, Jacksonville, Florida*

Remediation Technology

- Ethanol Co-Solvent Flushing

Site Description

- This is an inactive drycleaning facility that used PCE and operated intermittently from 1968 to 1989. From 1953 to the mid to late 1960s, the site was occupied by a service station. The site is located in a mixed commercial/residential setting.

Site Hydrogeology

- Depth to Water: 8 ft below land surface (bls)
- Unconfined Aquifer
  - Surface - 60 ft bls: silty fine to very fine-grained predominantly quartz sand, thin discontinuous clay present at ~ 35 ft bls
    - Hydraulic Gradient: 0.002 ft/ft
    - Hydraulic Conductivity: 10.35 ft/day
    - Seepage Velocity: 0.023 ft/day
  - 60 - 119 ft bls: clay and sandy, silty clay
  - 119 - 152 ft bls: clayey silt
- Groundwater Contamination
- Contaminants Present: PCE, TCE, cis 1,2-DCE, trans 1,2-DCE
- Highest Contaminant Concentrations: free-phase PCE was recovered from a monitor well, 34,000 μg/l TCE, 19,000 cis 1,2-DCE, 400 μg/l trans 1,2-DCE
- Deepest Contamination: 92 ft bls
- Plume Size: 0.35 acre (as defined to regulatory MCLs)

Remediation Scenario

- Treatment Area: 24 ft x 9 ft elliptical DNAPL source area with a targeted depth interval of 26 - 31 ft bls, maximum depth of pilot test was 35 ft bls
- Quantity: 9,000 gal of 95% ethanol and 5% water co-solvent
- Injection: 3 injection wells surrounded by 6 extraction wells with 7 multi-level samplers located between injection and extraction wells; co-solvent injection rate of 4 gallons per minute (gpm), extraction rate of 8 gpm over four days; ternary mixture of PCE/ethanol/water treated with Akzo Nobel Macro Porous Polymer (MPP) system for removal of PCE; approximately 160,000 gal of ethanol/water mixture disposed of offsite.

Results

- Demonstrated successful enhancement of dissolution and solubilization of DNAPL PCE. Recovered approximately 42 liters of DNAPL PCE representing approximately 63% of the estimated DNAPL PCE mass located within the source area.

Costs

- Approximately $440,000 including design, construction and operation.

Lessons Learned

1. Efficiency of the co-solvent flushing could be optimized through detailed tracer test evaluation and appropriate adjustments to the injection/extraction system.

2. Cost savings could be realized through alcohol re-use by limiting the total amount of alcohol necessary to complete flushing activities and decreasing disposal costs for wastewater with high alcohol concentration.

3. Residual ethanol remaining after co-solvent flushing has significantly enhanced in-situ biological dechlorination processes for natural attenuation of contaminant mass.

Cosolvent Flushing Pilot Test Report: Former Sages Dry Cleaner

In Situ Flushing at Former Sages Dry Cleaners, Jacksonville, Florida*

Contacts

Florida Dept. of Environmental Protection - Doug Fitton (850) 488-0190
LFR Levine-Fricke: Kevin Warner, P.E., (850) 422-2555

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* This is the complete report provided by the State Coalition of Dry Cleaners (*www.drycleancoalition.org*) for this project. A separate abstract for this project is not available.

Monitored Natural Attenuation at the Louisiana Army Ammunition Plant, Area P, Minden, Louisiana

Site Name:
Louisiana Army Ammunition Plant, Area P

Location:
Minden, Louisiana

Period of Operation:
Two years (dates not provided)

Cleanup Authority:
Not provided

EPA Contact:
Caroline Ziegler
U.S. EPA Region 6
1445 Ross Ave, Suite 1200
Dallas, TX 75202
(214) 665-2178

Purpose/Significance of Application:
Field demonstration of MNA for remediation of explosives

Cleanup Type:
Field demonstration

Contaminants:
Explosives
- TNT and RDX (groundwater concentrations as high as 24,000 ug/L)

Waste Source:
Loading, assembling, and packing of munitions

Principal Investigator:
Dr. Judith C. Pennington
U.S. Army Engr. Waterways Expt. Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
(601) 634-2802
penninj@ex1.wes.army.mil

Site Contact:
Doyle Williams
Environmental Officer
LAAP
Hwy 80
Minden, LA 71055
(318) 459-5108

Technology:
Monitored Natural Attenuation (MNA)
- Monitoring was conducted using monitoring wells (11 wells in which most analytes were consistently detected) and cone penetrometry (51 penetrations to 40 meters)
- Monitoring well samples were collected using a micropurge sampling technique

Type/Quantity of Media Treated:
Groundwater
- Geology is a complex stratigraphy of Pleistocene, terraced fluvial deposits unconformably overlying Eocene, nonmarine, massive sands, silty sands, silty clays, and occasional lignitic beds
- Site has clay lenses and silts, low porosity, and low organic carbon

Regulatory Requirements/Cleanup Goals:
- The objectives of the demonstration were to: (1) demonstrate that attenuation of explosives can be determined through appropriate site monitoring, (2) develop guidance for selection of MNA as a remedial alternative, (3) develop guidance for establishing a site monitoring plan and points of compliance, and (4) gain regulatory acceptance for use of MNA as an alternative for remediation of explosives
- Performance criteria included comparing actual concentrations of TNT and RDX in groundwater to the predicted concentrations based on site geology and hydrology; and observing transformation/degradation products of TNT and RDX

Results:
- Significant declines in contaminant concentrations were observed in 9 of the 11 monitoring wells over a two year period
- Contaminant mass was reduced from 52 to 50 metric tons for TNT, and from 78 to 68 metric tons for RDX

Costs:
- Overall cost of the demonstration was approximately $4,000,000, including costs for site characterization ($2,500,000), site monitoring, modeling, and development of biomarker techniques
- Costs for use of MNA in a full-scale application were projected to be 25% less than the costs for *in situ* bioremediation, and 50% less than the cost for pump and treat using activated carbon adsorption

Monitored Natural Attenuation at the Louisiana Army Ammunition Plant, Area P, Minden, Louisiana

Description:
The Louisiana Army Ammunition Plant, Area P (LAAP), in northwest Louisiana, was used for loading, assembling, and packing of munitions. Wastes from this site had been disposed of in 16 unlined lagoons. In the late 1980s, the lagoons had been pumped out and the sediment excavated and incinerated, and the area was capped with clay and topsoil. Site investigations revealed the presence of TNT and RDX in the groundwater at the site.

This site was selected for a field demonstration of MNA because the source of contamination had been removed, a large amount of groundwater monitoring data was available, and there were 50 monitoring wells in place. Two years of site monitoring showed that natural attenuation is occurring at LAAP, with decreases in contaminant concentrations and mass. Site capacity and biomarker techniques also contributed to the weight of evidence by estimating process rates. Numerical models predict significant continuing reductions in contaminant masses of TNT and RDX over a 20-year period. The overall cost of the demonstration was approximately $4,000,000, including costs for site characterization, site monitoring, modeling, and development of biomarker techniques.

Natural Attenuation of Chlorinated Solvents at Multiple Air Force Sites

Site Name:
Multiple Air Force Sites (14 total; refer to case study for names and locations of each site)

Location:
Multiple locations throughout U.S.

Period of Operation:
- Field demonstrations conducted between July 1993 and August 1999
- Periods of operation were not provided for each site

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Field demonstrations of monitored natural attenuation for chlorinated solvents in groundwater at multiple Air Force sites

Cleanup Type:
Field Demonstration

Contaminants:
Chlorinated Solvents
- Chlorinated aliphatic hydrocarbons, including TCE, cis- and trans-1,2-DCE, 1,1-DCE, and VC
- TCE was the most pervasive contaminant, followed by cis-1,2-DCE - found at 13 of 14 sites

Waste Source:
Not provided

Technical Contact:
Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, CO 80290

Management Contact:
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Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks AFB, TX 78235
E-mail:
jeff.cornell@hqafcee.brooks.af.mil

Technology:
Monitored Natural Attenuation (MNA)
- During the demonstrations, groundwater was sampled for contaminant concentrations, and other parameters including pH, temperature, conductivity, oxidation/reduction potential, dissolved oxygen, nitrate, nitrite, sulfate, sulfide, ferrous iron, total iron, and dissolved hydrogen; geochemical trends and biodegradation rates also were evaluated
- Four types of plume behavior were studies - Type 1 (anaerobic groundwater conditions with anthropogenic carbon); Type 2 (anaerobic groundwater conditions with native carbon); Type 3 (aerobic groundwater conditions with anthropogenic and/or native carbon); and mixed (different portions of the groundwater plume exhibiting different types of behavior)

Type/Quantity of Media Treated:
Groundwater
- Depths to groundwater ranged from 0 to 60 ft bgs
- Plume areas ranged from 1.6 to 210 acres
- Average groundwater temperatures ranged from 9.1 to 25.6 oC
- Aquifer matrices ranged from clays to coarse sand and gravel

Regulatory Requirements/Cleanup Goals:
- Goals of the demonstration included evaluating the potential for chlorinated solvents to be naturally attenuated, the type of attenuation processes taking place, and the effect on plume size

Results:
- Chlorinated solvents were undergoing natural attenuation at all 14 Air Force sites
- The degree and rate of intrinsic bioremediation was highly site-specific, and depended on the bio- and geo-chemistries of groundwater at the sites
- 11 of the sites exhibited mixed behavior, with nine exhibiting Type 1 coupled with either Type 2 or Type 3, and two sites exhibiting Type 2 behavior coupled with Type 3. Three of the sites exhibited primarily Type 1 behavior.
- With respect to plume size, three sites had expanding plumes, six sites had plumes that were either stable or expanding slowly, and five sites had plumes that were either stable or receding

Costs:
- The average cost per site in this demonstration for completing supplemental site characterization using existing monitoring wells and a Geoprobe®, laboratory and data analysis, fate and transport modeling, and reporting was $122,000
- A recommended long-term monitoring program for MNA, including an average network of 17 wells and 3 surface water stations, has a projected average annual monitoring cost of $22,800

Natural Attenuation of Chlorinated Solvents at Multiple Air Force Sites

Description:
In June 1993, the Air Force Center for Environmental Excellence (AFCEE), in cooperation with EPA/ORD, began an initiative to evaluate the effectiveness of MNA for remediation of groundwater contaminated with chlorinated solvents (also, refer to separate report about use of MNA for groundwater contaminated with fuel hydrocarbons). From 1993 to 1999, field demonstrations of MNA were conducted at 14 Air Force sites throughout the country. This included installing additional sampling points at the sites and collecting and evaluating data over a period of time.

The sites were evaluated for evidence that chlorinated solvents were being naturally attenuated, and to identify the degree and rate of attenuation. Data showed that chlorinated solvents were undergoing natural attenuation at all 14 Air Force sites, and that the degree and rate of intrinsic bioremediation was highly site-specific, and depended on the bio- and geo-chemistries of groundwater at the sites. The effect on plume size varied, with the plume expanding at three sites, remaining stable or expanding slowly at six sites, and remaining stable or receding at five sites. The study concluded that use of MNA for remediation of chlorinated solvents is highly site-specific, and that quantifying intrinsic bioremediation is difficult. The study states that engineered alternatives, such as source reduction, also should be evaluated to determine how they would limit plume migration and/or accelerate attainment of target cleanup levels.

Natural Attenuation of Fuel Hydrocarbons at Multiple Air Force Sites

Site Name:
Multiple Air Force Sites (42 total; refer to case study for names and locations of each site)

Location:
Multiple locations throughout U.S.

Period of Operation:
- Field demonstrations conducted between July 1993 and December 1998
- Periods of operation were not provided for each site

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Field demonstrations of monitored natural attenuation for fuel hydrocarbons in groundwater at multiple Air Force sites

Cleanup Type:
Field Demonstration

Contaminants:
BTEX, Total Petroleum Hydrocarbons (TPH)
- BTEX concentrations were measured as high as 46,300 ug/L (benzene), 57,000 ug/L (toluene), 4,410 ug/L (ethylbenzene), and 68,000 ug/L (xylenes)
- TPH concentrations were measured as high as 120,000 mg/L

Waste Source:
Not provided

Technical Contact:
Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, CO 80290

Management Contact:
Jeff Cornell
Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks AFB, TX 78235
E-mail:
jeff.cornell@hqafcee.brooks.af.mil

Technology:
Monitored Natural Attenuation (MNA)
- Intrinsic bioremediation including sulfate reduction, methanogenesis, denitrification, and aerobic oxidation
- During the demonstrations, groundwater was sampled for contaminant concentrations, and other parameters including pH, temperature, conductivity, oxidation/reduction potential, dissolved oxygen, nitrate, nitrite, sulfate, sulfide, ferrous iron, total iron, methane, carbon dioxide, and alkalinity; geochemical trends and biodegradation rates also were evaluated

Type/Quantity of Media Treated:
Groundwater
- Depths to groundwater ranged from 0 to 48 ft bgs
- Plume areas ranged from 0.3 to 60 acres
- Average groundwater temperatures ranged from 5.5 to 26.9 oC
- Aquifer matrices ranged from silty clays to coarse sand and gravel

Regulatory Requirements/Cleanup Goals:
- Goals of the demonstration included evaluating the potential for fuel hydrocarbons to be naturally attenuated, the type of biodegradation processes taking place, and the effect on plume size

Results:
- Fuel hydrocarbons were undergoing natural attenuation at all 42 Air Force sites
- Key biodegradation processes were identified, in decreasing order of assimilative capacity, as sulfate reduction, methanogenesis, iron reduction, denitrification, and aerobic oxidation; the total BTEX assimilative capacity of groundwater averaged 64 mg/L
- With respect to plume size, 35 sites had plumes that appeared to be stable, 6 sites had plumes that were receding, and 1 site had a plume that was expanding
- For sites with measurable free-phase product, the average predicted time frame for dissolved BTEX to naturally attenuate to below cleanup standards was estimated at approximately 30 years; the addition of engineered source reduction reduced the estimate to 20 years or less, depending on type of source reduction used
- Regulatory authorities have approved the partial or full use of MNA with institutional controls at 17 of the 42 sites

Costs:
- The average cost per site in this demonstration for completing site characterization using existing monitoring wells and a Geoprobe®, laboratory and data analysis, fate and transport modeling, and reporting was $125,000
- A recommended long-term monitoring program for MNA, including an average network of 11 wells, has a projected average annual cost of $192,000

Natural Attenuation of Fuel Hydrocarbons at Multiple Air Force Sites

Description:
In June 1993, the Air Force Center for Environmental Excellence (AFCEE), in cooperation with EPA/ORD, began an initiative to evaluate the effectiveness of MNA for remediation of groundwater contaminated with fuel hydrocarbons (also, refer to separate report about use of MNA for groundwater contaminated with chlorinated solvents). From 1993 to 1998, field demonstrations of MNA were conducted at 42 Air Force sites throughout the country. This included installing additional sampling points at the sites and collecting and evaluating data over a period of time.

The sites were evaluated for evidence that fuel hydrocarbons were being naturally attenuated, and to identify the degree and rate of attenuation. Data showed that fuel hydrocarbons were undergoing natural attenuation at all 42 Air Force sites, and that the degree and rate of intrinsic bioremediation was site-specific, involving processes such as sulfate reduction, methanogenesis, iron reduction, denitrification, and aerobic oxidation. The effect on plume size varied, with the plume stable at 35 sites, receding at 6 sites, and expanding at one site. For sites with measurable free-phase product, the average predicted time frame for dissolved BTEX to naturally attenuate to below cleanup standards was estimated at approximately 30 years; the addition of engineered source reduction reduced the estimate to 20 years or less, depending on type of source reduction used.

Soil Vapor Extraction and Groundwater Extraction Used at Eight Service Stations in Maryland

Site Name:
Multiple Retail Service Stations (site names confidential)

Location:
Maryland (specific locations not provided)

Period of Operation:
1990 – 1997; specific period of operation varies by site

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Use of Soil Vapor Extraction and Groundwater Extraction to treat soil and groundwater contaminated with MTBE and BTEX

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX
- Average MTBE concentration - 6,139 ug/L
- Average BTEX concentration - 5,511 ug/L

Waste Source:
Leaks from gasoline storage tanks

Site Contact:
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Chevron Research and Technology Company
100 Chevron Way
Richmond, CA 94802-0627
Telephone: (510) 242-5927
Fax: (510) 242-1380
E-mail: TRPE@chevron.com

Technology:
Soil Vapor Extraction and Groundwater Extraction (VE/GE)
- Remediation systems combined vapor extraction and groundwater extraction to treat smear-zone soils through dewatering and volatilization of contaminants
- SVE systems - number of vacuum extraction wells ranged from four to 17 at each site, with mean vacuums ranging from 22 to 41 inches of water, and air flow rates ranging from 4.6 to 18.5 scfm
- Groundwater extraction systems - number of groundwater extraction wells ranged from two to eight at each site, with the average pumping rate ranging from 0.11 to 0.67 gallons per minute

Type/Quantity of Media Treated:
Soil and Groundwater
- Four of the sites are located in the Coastal Plain Province and are characterized by alluvial sands, silts, and clay
- Four sites are located in the Piedmont Province and are characterized by saprolites (weathered bedrock) of schist and gneiss
- Hydraulic conductivities ranged from $3.4x\ 10^{-3}$ cm/sec to $7.1x\ 10^{-5}$ cm/sec.
- Pre-remediation depth to groundwater was <10 ft at one site, between 5-15 ft at a second site, and greater than 20 ft for the other 6 sites; water table varies from 2 to 13 ft
- Smear zone (located within or below the capillary fringe) is submerged most of the year; falling water table conditions (late summer and early fall) may increase NAPL saturation at the capillary fringe as a result of drainage from the newly formed vadose zone (lateral migration of NAPL)

Regulatory Requirements/Cleanup Goals:
According to Chevron, the objective of the VE/GE systems was smear-zone dewatering and remediation through volatilization. No specific cleanup goals were established for any of the sites.

Results:
- Average MTBE concentrations were reduced from 6,139 ug/L to 791 ug/L; BTEX from 5,511 ug/L to 1,088 ug/L; and xylene from 8,539 ug/L to 2,859 ug/L
- VE system removed approximately 1,300 kg to 95,000 kg of contaminants per site; GE system removed approximately 12 kg to 3,200 kg of contaminants per site
- For those sites where system shutdown had occurred, the average post-reduction rebound was –2.87% for MTBE, -9.12% for benzene, and 22.63% for xylene; while there was variation in rebound by individual wells at each site and among sites, on average, MTBE and BTEX concentrations did not generally rebound at sites after shutdown, while on average, there was rebound in xylene concentrations.

Soil Vapor Extraction and Groundwater Extraction Used at Eight Service Stations in Maryland

Costs:
No cost data were provided for these sites

Description:
At eight retail service stations in Maryland, Chevron Research and Technology Company used soil vapor extraction and groundwater extraction (VE/GE) to treat soil and groundwater contaminated with both MTBE and BTEX. A gasoline release had occurred at each site and had migrated to the water table and formed a smear zone (a volume of soil in the saturated aquifer that contains residual NAPL). The remediation systems combined vapor extraction and groundwater extraction to treat smear-zone soils through dewatering and volatilization of contaminants. The vacuum extraction systems at each site included vacuum extraction wells (ranging from 4 to 17 wells per site), one to two regenerative vacuum blowers used to generate an average air flow rate ranging from 4.6 to 18.5 scfm and a mean system vacuum ranging from 22 to 41 inches of water. The groundwater extraction system at each site included extraction wells (ranging from 2 to 8 wells per site) equipped with pneumatic total fluids pumps. The average pumping rate (water yield) ranged from 0.11 gpm to 0.67 gpm. The sites had an average remediation period of 3.2 years and an average monitoring period of 4.7 years.

The VE and GE systems removed between 1,330 and 95,000 kg and 12 to 3,200 kg of contaminants per site, respectively. Average contaminant concentrations at the sites were reduced to 791 ug/L for MTBE, 1,088 ug/L for BTEX, and 2,859 ug/L for xylene. For sites where the system had been shutdown, MTBE and BTEX concentrations did not generally rebound, whereas rebound was observed for xylene. According to the researchers, MTBE removal rates were found to be similar to those for BTEX, which was inconsistent with their assumptions of local chemical equilibrium for NAPL-liquid and NAPL-vapor partitioning. The researchers predicted removal rates for MTBE, based on several assumptions about local chemical equilibrium, were four times faster than benzene and 60 times faster than xylene. According to the researchers, while the reasons for this discrepancy were not known, it is likely that conventional groundwater remediation technologies will encounter similar mass removal limitations for MTBE and BTEX in all but ideal hydrogeologic settings.

Multi-Phase Extraction at Johanssen Cleaners, Lebanon, Oregon*

Remediation Technology

- Multiphase Extraction

Site Description

- Johannsen Cleaners began operations in 1955. In 1990, PCE contamination was discovered in an irrigation well in the area. Additional sampling over the next few years found PCE contamination in a number of private and domestic wells. From 1993-1995 work at the site indicated soil and groundwater contaminated with PCE.
- In late 1998, high levels of PCE soil contamination (to 68 mg/kg) were detected at the rear of the building and beneath the building along the sewer lines. In June 1999, approximately 37 tons of contaminated soil was removed and transported to a hazardous waste landfill. Excavation was to a depth of approximately three feet below the ground surface; a deeper excavation was not possible due to the proximity of the dry cleaner building and several power poles in the vicinity. Confirmation samples collected from the bottom of the excavation indicate that remaining soil concentrations range to 35 mg/kg in the center of the excavation.

Site Hydrogeology

- Alluvium containing gravel and sand with varying amounts of silt and clay.
- Vertical gradients in the area appear to be consistently downward. The average gradient between the shallow and deep aquifers in well clusters is about 20 times greater than the horizontal gradient in either aquifer.
  - Depth to Water: 10-15 feet
  - Upper Surficial Aquifer: 20-40 feet of silty sand
    - Hydraulic Gradient: 0.001 ft./ft.
    - Hydraulic Conductivity: ft./day
    - Seepage Velocity: ft./day.
  - Lower Regional Drinking Water Aquifer: n/a
    - Hydraulic Gradient: n/a
    - Hydraulic Conductivity: n/a
    - Seepage Velocity: n/a

Groundwater Contamination

- Contaminants Present: PCE, trichloroethene (TCE), cis 1,2-dichloroethene (cis- DCE), and vinyl chloride (VC)
- Highest Contaminant Concentrations: 3,400 mg/l PCE, 42 mg/l TCE, 41 mg/l cis 1,2-DCE and VC 2.7 ug/l.
- Deepest Contamination: ~120 feet below ground surface (bgs.) in deeper drinking water aquifer. Full characterization not yet available.

Remediation Scenario

- System consists of two horizontal headers with vertical wells to the groundwater table. System removes soil vapor and groundwater from beneath the building slab. Soil vapor and groundwater are treated via air stripping and/or direct discharge to the atmosphere.

Results

- Discharge Vapor: 14,000-180,000 ug/m^3
- Discharge water: ~1,000 ug/l

Costs

- Overall Project - $ 230,000
- System design - $ 15-25,000
- Build/install - $45-60,000

Multi-Phase Extraction at Johanssen Cleaners, Lebanon, Oregon*

Lessons Learned

1. Sewer discharge pipe ruptured. Need for upgrade/construction not realized.

2. Piping runs beneath flooring provided ideal access points to measure vacuum effect of treatment system.

3. 20/20 hindsight. Based on other sites, money may have been better spent on alternative cleanup/remediation (e.g., HRC, bioremediation) rather than active treatment. However, at the time, HRC was not recommended in a DNAPL zone (1% rule of thumb) and other delivery methods proved problematic.

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* This is the complete report provided by the State Coalition of Dry Cleaners (*www.drycleancoalition.org*) for this project. A separate abstract for this project is not available.

Multi-Phase Extraction Using Fluidized Bed Reactor and Granular Activated Carbon at the Sparks Solvent/Fuel Superfund Site

Site Name:
Sparks Solvent/Fuel Superfund Site

Location:
Sparks, Nevada

Period of Operation:
1995 to present (performance data available through August 1997)

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Use of multiphase extraction using fluidized bed reactor and granular activated carbon to treat MTBE in groundwater

Cleanup Type:
Full scale

Contaminants:
MTBE, BTEX, PCE, TCE
- MTBE concentrations as high as 600 ug/L
- BTEX concentrations as high as 1,272 ug/L
- PCE concentrations as high as 7.6 ug/L
- TCE concentrations as high as 42 ug/L

Waste Source:
Leaks from bulk petroleum and gasoline storage tanks

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Technology:
Multi-Phase Extraction (MPE) using Fluidized Bed Reactor (FBR) and Granular Activated Carbon (GAC)
- Groundwater extraction system includes 29 multi-phase wells; extracted groundwater directed to a product/water separator; free product is recovered; separated water is sent to the FBR system
- FBR system includes two U.S. Filter/Envirex GAC FBR reactors operated in parallel; total design flow is 550 gpm
- Influent water enters the bottom of the reactor tank and flows upward through the GAC/biofilm substrate where organic compounds are absorbed and degraded

Type/Quantity of Media Treated:
Groundwater

Regulatory Requirements/Cleanup Goals:
- Not provided

Multi-Phase Extraction Using Fluidized Bed Reactor and Granular Activated Carbon at the Sparks Solvent/Fuel Superfund Site

Results:
- At the early portion of system operation, MTBE removal efficiencies were greater than 90%. After six weeks of operation, removal efficiencies fell to 10%
- To accelerate MTBE degradation, 20 gallons of a GAC inoculum were added to one of the reactors (FBR1) in April 1996; the removal efficiency initially increased to about 40% and continued to increase to over the next five months to about 75%
- For the reactor that did not receive the inoculum, the removal efficiency continued to remain low for another month, then began increasing to similar levels as the reactor that had received the inoculum
- As of August 1997 (650 days of operation), the removal efficiency for MTBE was about 90%, and MTBE concentrations were below10 ug/L in the effluent from the FBR system.
- Data for BTEX, TPH, and chlorinated solvents was provided for the first year of operation**.** The removal rate was >99% for BTEX, 78% for TPH, and about 50% for both PCE and TCE

Costs:
- No cost data were provided for this application.

Description:
The Sparks Solvent/Fuel Site is an industrial area in Sparks, Nevada, which contains a rail yard, a bulk petroleum storage facility, and warehouses. The site is located near the Truckee River, which supplies the majority of the drinking water to the Reno-Sparks metropolitan area. In 1987, a contaminant plume consisting of petroleum hydrocarbons, MTBE, and chlorinated solvents (PCE and TCE) was identified as originating beneath the site, and extending more than one mile from the site. MTBE had been used as an additive to gasoline stored at the site. EPA, in conjunction with the Nevada Division of Environmental Protection, issued an administrative order requiring cleanup of the site.

In 1995, a groundwater extraction and treatment system was installed at the site. The system began operating in late October 1995 and operations were ongoing at the time of this report. The groundwater extraction system includes multi-phase extraction wells designed to provide source control and hydraulic containment. Extracted groundwater is treated using granulated activated carbon (GAC) and fluidized bed bioreactors (FBRs) to aerobically treat MTBE and other petroleum contaminants as well as chlorinated aliphatic solvents. MTBE data, available through August 1997, show MTBE concentrations were below10 ug/L in the effluent from the FBR system, with a removal rate of 90%. Data for other contaminants, available for the first year of operation, show a removal rate for BTEX of >99%, TPH of 78%, PCE of 50%, and TCE of 50%.

Permeable Reactive Barrier at Monticello Mill Tailings Site, Monticello, Utah

Site Name:
Monticello Mill Tailings Site

Location:
Monticello, UT

Period of Operation:
June 1999

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Demonstration of permeable reactive barrier to treat heavy metals in groundwater

Cleanup Type:
Field Demonstration

Contaminants:
Heavy Metals
- Average concentrations in late 1999 were uranium (700 ug/L), vanadium (400 ug/L), selenium (40 ug/L), and arsenic (10 ug/L)

Waste Source:
Milling activities

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Technology:
Permeable Reactive Barrier (PRB)
- The PRB used a funnel and gate design, with impermeable walls north and south of a reactive media gate
- The gate consisted of three sections: (1) an upstream gravel with a zero-valent iron (ZVI) pretreatment zone; (2) a middle portion of granular ZVI; and (3) a downstream gravel pack with an air sparging system
- The northern wall was 30 meters (m) long, the southern wall 75 m long, and the gate 30 m long; the gate had a 0.6 m pretreatment zone and a 1 m granular ZVI zone, and was 3.5 to 7 m deep
- More than 60 groundwater monitoring wells were installed at the site

Type/Quantity of Media Treated:
Groundwater
- The site has an alluvial, unconsolidated aquifer containing mostly sand with minor amounts of gravel and clay
- Impermeable bedrock is present at 4 to 8 m bgs

Regulatory Requirements/Cleanup Goals:
Evaluate changes in concentrations of heavy metals through the PRB

Results:
- The concentrations of uranium, vanadium, selenium, and arsenic were reduced to non detectable levels in groundwater down-gradient of the PRB, after the water had passed through the ZVI-filled gate
- Iron and manganese were present in the effluent from the gate at concentrations lower than predicted by treatability studies

Costs:
- Actual cost for the PRB was $1,196,000, consisting of $1,052,000 for construction and $144,000 for media
- A projected comparison between PRB and pump and treat technology at this site showed that total life cycle costs are 10 times less for the PRB than for the pump and treat system

Permeable Reactive Barrier at Monticello Mill Tailings Site, Monticello, Utah

Description:
In June 1999, a permeable reactive barrier wall, also referred to as a permeable reactive treatment (PeRT) wall, was installed at DOE's Monticello Mills Tailings Site (MMTS), a former uranium and vanadium ore-processing mill in Monticello Utah. The MMTS operated from the mid-1940s to 1960, and was placed on the NPL in 1989 because of contaminated materials from past milling activities. A federal facility agreement specifies DOE as the lead agency for cleanup, with oversight to EPA and the State.

The PRB used a funnel and gate design, with impermeable walls north and south of a reactive media gate. The gate consisted of an upstream gravel with a zero-valent iron (ZVI) pretreatment zone; a middle portion of granular ZVI; and a downstream gravel pack with an air sparging system. The concentrations of uranium, vanadium, selenium, and arsenic were reduced to non detectable levels in groundwater down-gradient of the PRB, after the water had passed through the ZVI-filled gate. The researchers attributed the success of the design to the use of a pretreatment zone, consisting of mostly gravel with minor amounts of ZVI, at the leading edge of the gate. This zone was thought to initiate the reduction reactions within a very porous media that was not likely to clog.

CONTAINMENT ABSTRACTS

Vertical Engineered Barrier at Dover Air Force Base, Groundwater Remediation Field Laboratory National Test Site, Dover, Delaware

Site Name:
Dover Air Force Base, Groundwater Remediation Field Laboratory National Test Site

Location:
Dover, DE

Period of Operation:
10/96 - 9/98

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Demonstration of vertical engineered barrier using thin diaphragm walls

Cleanup Type:
Field Demonstration

Contaminants:
None

Waste Source:
Not applicable - clean test site

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Technology:
Vertical Engineered Barrier (VEB)
- VEB consisted of cement bentonite thin diaphragm walls, installed using high-pressure jet grouting
- Project conducted in two phases - Phase 1 consisted of creating four small barrier boxes to refine grouting parameters; Phase 2 consisted of creating two cofferdams, each 34 feet (ft) in diameter, and consisting of 12 interconnecting thin diaphragm walls (each wall 13 to 16 ft long)
- The cofferdams were constructed by jetting a cement/bentonite slurry 7 ft into the underlying clay confining unit (a total depth of 43 ft bgs); one cofferdam was covered with a geomembrane to prevent infiltration
- The integrity of the cofferdams was tested using pump tests, pulse tests, flood tests, and geophysical techniques

Type/Quantity of Media Treated:
Groundwater
- Depth to groundwater 26 ft
- The upper aquifer consists of sand with lenses of gravel and clay, and has hydraulic conductivity ranging from 2.8×10^{-3} to 1.2×10^{-2} cm/sec
- Clay confining unit present at 36 ft bgs

Regulatory Requirements/Cleanup Goals:
Project objectives were to demonstrate:
- Construction of a high-pressure, jet grouted, thin-diaphragm containment barrier
- Performance of the barrier using several verification and monitoring methods
- Hydraulic conductivity performance goal of 1×10^{-7} cm/sec

Results:
- Hydraulic testing showed no defects in the upper 25 ft (unsaturated zone) of the cofferdam; one defect was identified in the lower 10 ft of the second cofferdam - the defect was associated with a thin zone of higher hydraulic conductivity
- Hydraulic testing also showed that the cofferdams met the hydraulic conductivity performance goal, at all except one location

Costs:
- A unit cost of $\$6.71/\text{ft}^2$ was projected for constructing two single-wall cofferdam barriers using thin-diaphragm panels at a hypothetical site with a depth of 43 ft and a length of 40 ft; this cost did not include cement or bentonite materials, mobilization/demobilization, spoils disposal, or costs associated with a guidance tool
- A unit cost of $\$8.21/\text{ft}^2$ was projected for constructing a thin-diaphragm wall cofferdam at the Dover AFB test site, including mobilization and demobilization; costs for construction at a low level radioactive waste site were projected to be significantly higher

Vertical Engineered Barrier at Dover Air Force Base, Groundwater Remediation Field Laboratory National Test Site, Dover, Delaware

Description:
During fall 1997, a demonstration of high-pressure jet grouting to emplace thin-diaphragm walls was conducted at the Groundwater Remediation Field Laboratory (GRFL) National Test Site at the Dover Air Force Base. Two cofferdams were constructed, consisting of 12 interconnecting cement bentonite, thin-diaphragm walls. Hydraulic testing also showed that the cofferdams met the hydraulic conductivity performance goal of 1×10^{-7} cm/sec, at all except one location. A projected unit cost of \$8.21/ft^2 was identified for constructing a thin-diaphragm wall cofferdam at the Dover AFB test site, including mobilization and demobilization; costs for construction at a low level radioactive waste site were projected to be significantly higher.

Landfill Cap at Sandia National Laboratories, Albuquerque, New Mexico

Site Name:
Sandia National Laboratories

Location:
Albuquerque, NM

Period of Operation:
July 1995 to July 2000

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Field demonstration of alternative landfill covers

Cleanup Type:
Field Demonstration

Contaminants:
None

Waste Source:
None - clean site

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Technology:
Cap
- Four alternative landfill cover designs were demonstrated: (1) a geosynthetic clay liner (GCL) cover; (2) a capillary barrier cover; (3) an anisotropic barrier cover; and (4) an evapotranspiration (ET) soil cover
- Design characteristics included
- GCL cover: 90 cm thickness, 4 layers
- capillary barrier cover: 140 cm thickness, 4 layers
- anisotropic barrier cover: 105 cm thickness, 4 layers
- ET soil cover: 90 cm thickness, 2 layers
- These alternative covers were compared with conventional RCRA Subtitle C and D covers
- Each demonstration plot was 13 m wide by 100 m long, with the long dimension crowned in the middle; all layers had a 5% grade; the western slope was maintained at ambient conditions, and a sprinkler was installed on the eastern slope

Type/Quantity of Media Treated:
Soil

Regulatory Requirements/Cleanup Goals:
- The following soil properties were used to evaluate performance: soil moisture, soil temperature, runoff and erosion, percolation and inter-flow, meteorology, and vegetation

Results:
- Preliminary water flux rate data showed that all cover designs, except the RCRA Subtitle D cover, were impermeable; the anisotropic and ET covers had efficiencies similar to the RCRA Subtitle C cover
- Additional findings included:
- GCL: did not perform as well as expected
- capillary barrier cover: the percolation rate for the first year was higher than expected, and slowed significantly in later years
- anisotropic barrier cover: performed well
- ET soil cover: performed well

Costs:
- Actual unit construction costs were provided for the six covers; these included mobilization/demobilization, sub-grade preparation, materials, and labor
- Unit costs were: GCL cover - \$89.99/m^2; capillary barrier cover - \$92.64/m^2; anisotropic barrier cover - \$75.26/m^2; ET cover - \$73.89/m^2; RCRA Subtitle C cover - \$157.54/m^2; RCRA Subtitle D - \$51.40/m^2

Landfill Cap at Sandia National Laboratories, Albuquerque, New Mexico

Description:
A field demonstration of four alternative landfill covers was conducted at the Sandia National Laboratories in Albuquerque, New Mexico. The four covers - GCL, capillary barrier, anisotropic barrier, and ET - were compared in a side-by-side demonstration with RCRA Subtitles C and D covers. Each of the six demonstration plots was 13 m wide by 100 m long, and crowned in the middle. Results showed that all cover designs, except the RCRA Subtitle D cover, were impermeable, and that the anisotropic and ET covers had efficiencies similar to the RCRA Subtitle C cover. Based on the results from this study, an ET cover was selected to be deployed at the Mixed Waste Landfill at Sandia. The ET cover was projected to save $7.6 million over a 30 year period when compared with use of a RCRA Subtitle C cover.

APPENDIX A

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Soil Vapor Extraction (31 Projects)					
Basket Creek Surface Impoundment Site, GA	Soil Vapor Extraction	Soil (*ex situ*)	BTEX (Toluene), Ketones (MIBK)	1992	1997
Camp Lejeune Military Reservation, Site 82, Area A, NC	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1995	1998
Commencement Bay, South Tacoma Channel Well 12A Superfund Site, WA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1992	1995
Davis-Monthan AFB, Site ST-35, AZ	Soil Vapor Extraction	Soil (*in situ*)	BTEX/TPH	1995	1998
Defense Supply Center Richmond, OU 5, VA	Soil Vapor Extraction (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1992	1998
Fairchild Semiconductor Corporation Superfund Site, CA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1989	1995
Fort Greely, Texas Tower Site, AK	Soil Vapor Extraction, Air Sparging, *In Situ* Bioremediation	Soil (*in situ*)	BTEX/TPH	1994	1998
Fort Lewis, Landfill 4, WA	Soil Vapor Extraction, Air Sparging	Soil (*in situ*)	Chlorinated Solvents, Metals	1994	1998
Fort Richardson, Building 908 South, AK	Soil Vapor Extraction	Soil (*in situ*)	BTEX/TPH	1995	1998
Hastings Groundwater Contamination Superfund Site, Well Number 3 Subsite, NE	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1992	1995
Holloman AFB, Sites 2 and 5, NM	Soil Vapor Extraction	Soil (*in situ*)	BTEX/TPH	1994	1998
Idaho National Engineering and Environmental Laboratory, ID	Soil Vapor Extraction (Soil Venting) (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1996	2000
Intersil/Siemens Superfund Site, CA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1988	1998
Luke Air Force Base, North Fire Training Area, AZ	Soil Vapor Extraction	Soil (*in situ*)	BTEX/TPH	1990	1995
McClellan Air Force Base, Operable Unit D, Site S, CA	Soil Vapor Extraction (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1993	1995

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
NAS North Island, Site 9, CA	Soil Vapor Extraction (Photolytic Destruction) (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1997	1998
Patrick Air Force Base, Active Base Exchange Service Station, FL	Soil Vapor Extraction (Biocube^{TM}) (Field Demonstration)	Soil (*in situ*)	BTEX/TPH	1994	2000
Patrick Air Force Base, Active Base Exchange Service Station, FL	Soil Vapor Extraction (Internal Combustion Engine) (Field Demonstration)	Soil (*in situ*)	BTEX/TPH	1993	2000
Rocky Mountain Arsenal Superfund Site (Motor Pool Area - Operable Unit #18), CO	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1991	1995
Sacramento Army Depot Superfund Site, Burn Pits Operable Unit, CA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents - TCE, PCE, DCE	1994	1997
Sacramento Army Depot Superfund Site, Tank 2 (Operable Unit #3), CA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated and Non-Chlorinated Solvents	1992	1995
Sand Creek Industrial Superfund Site, Operable Unit 1, CO	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents - PCE, TCE	1993	1997
Seymour Recycling Corporation Superfund Site, IN	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1992	1998
Shaw AFB, OU 1, SC	Soil Vapor Extraction, Groundwater Containment	Soil (*in situ*)	BTEX/TPH	1995	1998
SMS Instruments Superfund Site, NY	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated and Non-Chlorinated Solvents	1992	1995
Tyson's Dump Superfund Site, PA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1988	1998
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH	Soil Vapor Extraction (*In Situ* Enhanced Soil Mixing) (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents - TCE, DCE, TCA	1992	1997
U.S. Department of Energy, Savannah River Site, SC	Soil Vapor Extraction (Flameless Thermal Oxidation) (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents - TCE, PCE, TCA	1995	1997
U.S. Department of Energy, Savannah River Site, SC, and Sandia, NM	Soil Vapor Extraction (Horizontal Wells) (Field Demonstration)	Soil (*in situ*) and Groundwater	Chlorinated Solvents	1988	2000

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Vandenberg Air Force Base, Base Exchange Service Station, CA	Soil Vapor Extraction (Resin Adsorption) (Field Demonstration)	Soil (*in situ*)	BTEX/TPH	1994	2000
Verona Well Field Superfund Site (Thomas Solvent Raymond Road - Operable Unit #1), MI	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated and Non-Chlorinated Solvents	1988	1995
Other *In Situ* Soil Treatment (25 Projects)					
Active Power Substation, Confidential Location	Electrokinetics (Field Demonstration)	Soil (*in situ*)	Metals	1998	2000
Alameda Point, CA	Electrokinetics (Field Demonstration)	Soil (*in situ*)	Metals	1997	2001
Argonne National Laboratory - East, IL	Phytoremediation (Field Demonstration)	Soil (*in situ*)	Metals	1998	2000
Brodhead Creek Superfund Site, PA	Contained Recovery of Oily Waste	Soil (*in situ*)	PAHs, Metals	1995	1998
Dover Air Force Base, Building 719, DE	Bioventing (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1998	2000
Eielson Air Force Base, AK	Bioventing (Field Demonstration)	Soil (*in situ*)	BTEX/TPH	1991	1995
Ensign-Bickford Company - OB/OD Area, CT	Phytoremediation	Soil (*in situ*)	Metals	1998	2000
Former Mare Island Naval Shipyard, CA	*In Situ* Thermal Desorption (Field Demonstration)	Soil (*in situ*)	PCBs	1997	2000
Fort Richardson Poleline Road Disposal Area, OU B, AK	Six Phase Heating (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1997	2000
Hill Air Force Base, Site 280, UT	Bioventing	Soil (*in situ*)	BTEX/TPH	1990	1995
Hill Air Force Base, Site 914, UT	Bioventing, Soil Vapor Extraction	Soil (*in situ*)	BTEX/TPH	1988	1995
Lowry Air Force Base, CO	Bioventing	Soil (*in situ*)	BTEX/TPH	1992	1995
Missouri Electric Works Superfund Site, MO	*In Situ* Thermal Desorption (Field Demonstration)	Soil (*in situ*)	PCBs	1997	1998
Multiple Air Force Test Sites, Multiple Locations	Bioventing (Field Demonstration)	Soil (*in situ*)	BTEX/TPH	1992	2000

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Naval Air Weapons Station Point Mugu, Site 5, CA	Electrokinetics (Field Demonstration)	Soil (*in situ*)	Metals	1998	2000
Parsons Chemical/ETM Enterprises Superfund Site, MI	*In Situ* Vitrification	Soil (*in situ*)	Pesticides, Metals, Dioxins	1993	1997
Portsmouth Gaseous Diffusion Plant, X-231A Site, Piketon, OH	Hydraulic Fracturing (Field Demonstration)	Soil (*in situ*) and Groundwater	Chlorinated Solvents	1996	2001
Sandia National Laboratories, Unlined Chromic Acid Pit, NM	Electrokinetics (Field Demonstration)	Soil (*in situ*)	Metals	1996	2000
Twin Cities Army Ammunition Plant, MN	Phytoremediation (Field Demonstration)	Soil (*in situ*)	Metals	1998	2000
White Sands Missile Range, SWMU 143, NM	Chemical Reduction/Oxidation (Field Demonstration)	Soil (*in situ*)	Metals	1998	2000
U.S. Department of Energy Hanford Site, WA, Oak Ridge (TN) and Others	*In Situ* Vitrification	Soil (*in situ*)	Pesticides, Metals, Dioxins/Furans, PCBs	Not Provided	1997
U.S. Department of Energy, Multiple Sites	Resonant Sonic Drilling (Field Demonstration)	Soil (*in situ*)	Not Applicable (not a contaminated site)	1992	1997
U.S. Department of Energy Paducah Gaseous Diffusion Plant, KY	Lasagna™ Soil Remediation (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents - TCE	1995	1997
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH and Other Sites	Hydraulic and Pneumatic Fracturing (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents, DNAPLs	1991	1997
U.S. Department of Energy, Savannah River Site, SC, and Hanford Site, WA	Six Phase Soil Heating (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents - TCE, PCE	1993	1997

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Incineration (on-site) (18 Projects)					
Baird and McGuire, MA	Rotary Kiln Incinerator	Soil, Sediment	PAHs, Pesticides/Herbicides, Metals, Dioxins, PCBs	1995	1998
Bayou Bonfouca, LA	Rotary Kiln Incinerator	Sediment, Other Material	PAHs	1993	1998
Bridgeport Refinery and Oil Services, NJ	Rotary Kiln Incinerator	Soil, Sediment, Sludge, Debris	BTEX/TPH, Metals, Dioxins, PCBs	1991	1998
Celanese Corporation Shelby Fiber Operations, NC	Rotary Kiln Incinerator	Soil, Sludge	Chlorinated Solvents, PAHs, Metals	1991	1998
Coal Creek, WA	Rotary Kiln Incinerator	Soil	Metals, Dioxins, PCBs	1994	1998
Drake Chemical Superfund Site, Operable Unit 3, Lock Haven, PA	Rotary Kiln Incinerator	Soil	Chlorinated Solvents, Volatiles - Nonhalogenated	1998	2001
FMC Corporation - Yakima, WA	Rotary Kiln Incinerator	Soil, Debris	Pesticides/Herbicides, Metals	1993	1998
Former Nebraska Ordnance Plant - OU 1, NE	Rotary Kiln Incinerator	Soil, Debris	Explosives/Propellants - TNT, RDX, HMX	1997	1998
Former Weldon Springs Ordnance Works, OU 1, MO	Rotary Kiln Incinerator	Soil	Explosives/Propellants	1998	2000
MOTCO, TX	Rotary Kiln Incinerator	Soil, Sludge, Liquids	Chlorinated Solvents, Metals, Dioxins, PCBs	1990	1998
Old Midland Products, AR	Rotary Kiln Incinerator	Soil, Sludge	PAHs	1992	1998
Petro Processors, LA	Horizontal Liquid Injection Incinerator	Liquids, Fumes	Chlorinated Solvents, BTEX/TPH, PAHs, Metals	1994	1998
Rocky Mountain Arsenal, CO	Submerged Quench Incinerator	Liquids	Pesticides/Herbicides, Metals	1993	1998

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Rose Disposal Pit, MA	Rotary Kiln Incinerator	Soil	Chlorinated Solvents, Dioxins, PCBs	1994	1998
Rose Township Dump, MI	Infrared Incinerator	Soil	BTEX/TPH, Dioxins, PCBs	1992	1998
Sikes Disposal Pits, TX	Rotary Kiln Incinerator	Soil, Debris	Chlorinated Solvents, PAHs	1992	1998
Times Beach, MO	Rotary Kiln Incinerator	Soil, Debris	Dioxins, PCBs	1996	1998
Vertac Chemical Corporation, AR	Rotary Kiln Incinerator	Soil, Waste, Drums	Pesticides/Herbicides, Dioxins, PCBs	1992	1998
Thermal Desorption (22 Projects)					
Anderson Development Company Superfund Site, MI	Thermal Desorption	Soil	Semivolatile - Nonhalogenated (MBOCA), PAHs	1992	1995
Arlington Blending and Packaging Superfund Site, TN	Thermal Desorption	Soil	Pesticides/Herbicides, Metals	1996	2000
FCX Washington Superfund Site, NC	Thermal Desorption	Soil	Pesticides/Herbicides	1995	1998
Fort Lewis, Solvent Refined Coal Pilot Plant (SRCPP), WA	Thermal Desorption	Soil	PAHs	1996	1998
Letterkenny Army Depot Superfund Site, K Areas, OU1, PA	Thermal Desorption	Soil	Chlorinated Solvents, Metals	1993	2000
Longhorn Army Ammunition Plant, Burning Ground No. 3, TX	Thermal Desorption	Soil	Chlorinated Solvents	1997	2000
McKin Superfund Site, ME	Thermal Desorption	Soil	BTEX/TPH, PAHs	1986	1995
Metaltec/Aerosystems Superfund Site, Franklin Borough, NJ	Thermal Desorption	Soil	Chlorinated Solvents	1994	2001
Naval Air Station Cecil Field, Site 17, OU 2, FL	Thermal Desorption	Soil	BTEX/TPH, PAHs	1995	1998

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
New Bedford Harbor Superfund Site, New Bedford, MA	Thermal Desorption (Field Demonstration)	Soil	PCBs	1996	2001
Outboard Marine Corporation Superfund Site, OH	Thermal Desorption	Soil	PCBs	1992	1995
Port Moller Radio Relay Station, AK	Thermal Desorption	Soil	BTEX/TPH	1995	1998
Pristine, Inc. Superfund Site, OH	Thermal Desorption	Soil	BTEX, PAHs, Pesticides, Dioxins, Chlorinated Solvents	1993	1995
Reich Farm, Pleasant Plains, NJ	Thermal Desorption	Soil	Chlorinated Solvents, Other Volatiles and Semivolatiles (not specified)	1994	2001
Re-Solve, Inc. Superfund Site, MA	Thermal Desorption	Soil	PCBs	1993	1998
Rocky Flats Environmental Technology Site, Mound Site, Golden, CO	Thermal Desorption	Soil	Chlorinated Solvents	1997	2001
Rocky Flats Environmental Technology Site, Trenches T-3 and T-4, CO	Thermal Desorption	Soil	Chlorinated Solvents, Radionuclides	1996	2000
Sand Creek Superfund Site, OU 5, CO	Thermal Desorption	Soil	Pesticides, Metals	1994	2000
Sarney Farm, Amenia, NY	Thermal Desorption	Soil	Chlorinated Solvents, Ketones, BTEX	1997	2001
TH Agriculture & Nutrition Company Superfund Site, GA	Thermal Desorption	Soil	Pesticides	1993	1995
Waldick Aerospaces Devices Superfund Site, NJ	Thermal Desorption	Soil	Chlorinated Solvents, BTEX/TPH, Metals	1993	1998
Wide Beach Development Superfund Site, NY	Thermal Desorption w/Dehalogenation	Soil	PCBs	1990	1995

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Other *Ex Situ* Soil Treatment (31 Projects)					
Bonneville Power Administration Ross Complex, Operable Unit A, WA	Land Treatment	Soil	PAHs	1994	1998
Brookhaven National Laboratory, NY	Physical Separation/Segmented Gate System	Soil	Radionuclides	2000	2001
Brown Wood Preserving Superfund Site, FL	Land Treatment	Soil	PAHs	1989	1995
Burlington Northern Superfund Site, MN	Land Treatment	Soil	PAHs, Methylene Chloride Extractable Hydrocarbons (TPH)	1986	1997
Dubose Oil Products Co. Superfund Site, FL	Composting	Soil	PAHs, BTEX (Toluene), Chlorinated Solvents - TCE	1993	1997
Envirocare of Utah, UT	Polyethylene Macroencapsulation (Field Demonstration)	Soil	Radionuclides	1996	1998
Fort Greely, UST Soil Pile, AK	Land Treatment	Soil	BTEX/TPH	1994	1998
Fort Polk Range 5, LA	Acid Leaching (Field Demonstration)	Soil	Metals	1996	2000
French Ltd. Superfund Site, TX	Slurry-Phase Bioremediation	Soil	BTEX, PAHs, Chlorinated Solvents	1992	1995
Idaho National Environmental and Engineering Laboratory (INEEL), ID	Physical Separation/Segmented Gate System	Soil	Radionuclides	1999	2001
Joliet Army Ammunition Plant, IL	Slurry-Phase Bioremediation(Field Demonstration)	Soil	Explosives/Propellants	1994	2000
King of Prussia Technical Corporation Superfund Site, NJ	Soil Washing	Soil	Metals	1993	1995
Los Alamos National Laboratory, NM	Physical Separation; Segmented Gate System	Soil	Radionuclides	1999	2000
Lowry Air Force Base, CO	Land Treatment	Soil	BTEX/TPH	1992	1995

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Massachusetts Military Reservation, Training Range and Impact Area, Cape Cod, MA	Solidification/Stabilization	Soil	Metals, Lead	1998	2001
New Bedford Harbor Superfund Site, New Bedford, MA	Solidification/Stabilization (Field Demonstration)	Soil	PCBs	1995	2001
New Bedford Harbor Superfund Site, New Bedford, MA	Solvent Extraction (Field Demonstration)	Soil	PCBs	1996	2001
New Bedford Harbor Superfund Site, New Bedford, MA	Vitrification (Field Demonstration)	Soil	PCBs	1996	2001
Novartis Site, Ontario, Canada	Land Treatment (Field Demonstration)	Soil	Pesticides/Herbicides	1996	1998
Oak Ridge National Laboratory, TN	Vitrification (Field Demonstration)	Soil	Metals, Radionuclides	1997	2000
Pantex Plant, Firing Site 5, TX	Physical Separation; Segmented Gate System	Soil	Radionuclides	1998	2000
RMI Titanium Company Extrusion Plant, OH	Solvent Extraction (Field Demonstration)	Soil	Metals, Radionuclides	1997	2000
Sandia National Laboratories, ER Site 228A, NM	Physical Separation; Segmented Gate System	Soil	Radionuclides	1998	2000
Sandia National Laboratories, ER Site 16, NM	Physical Separation; Segmented Gate System	Soil	Radionuclides	1998	2000
Scott Lumber Company Superfund Site, MO	Land Treatment	Soil	PAHs	1989	1995
Southeastern Wood Preserving Superfund Site, MS	Slurry-Phase Bioremediation	Soil	PAHs - Naphthalene, Benzo(a)pyrene	1991	1997
Sparrevohn Long Range Radar Station, AK	Solvent Extraction	Soil	PCBs	1996	1998
Stauffer Chemical Company, Tampa, FL	Composting (Field Demonstration)	Soil	Organochlorine Pesticides	1997	2001
Tonapah Test Range, Clean Slate 2, NV	Physical Separation; Segmented Gate System	Soil	Radionuclides	1998	2000

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Umatilla Army Depot Activity, OR	Windrow Composting (Field Demonstration)	Soil	Explosives/Propellants -TNT, RDX, HMX	1992	1995
Umatilla Army Depot Activity, OR	Windrow Composting	Soil	Explosives/Propellants -TNT, RDX, HMX	1994	1997
Drinking Water Treatment (3 Projects)					
Charnock Wellfield, Santa Monica, CA	Drinking Water Treatment (Field Demonstration)	DrinkingWater	MTBE, VOCs	1998	2001
Lacrosse, KS	Drinking Water Treatment	DrinkingWater	MTBE, BTEX/TPH	1997	2001
Rockaway, NJ	Drinking Water Treatment	DrinkingWater	MTBE, Chlorinated Solvents, Volatiles-Nonhalogenated	1980	2001
Pump and Treat (42 Projects)					
Amoco Petroleum Pipeline, MI	Pump and Treat with GAC	Groundwater	BTEX/TPH	1988	1995
Baird and McGuire Superfund Site, MA	Pump and Treat with Air Stripping, Chemical Treatment, and Filtration	Groundwater	BTEX/TPH, PAHs, Pesticides/Herbicides, Metals	1993	1998
Bofors Nobel Superfund Site, OU 1, MI	Pump and Treat with Air Stripping, GAC, Chemical Treatment, Filtration, and UV/Oxidation	Groundwater	Chlorinated Solvents, Semivolatiles	1994	1998
City Industries Superfund Site, FL	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents, BTEX/TPH	1994	1998
Coastal Systems Station, AOC 1, FL	Chemical Reaction and Dissolved Air Flotation (Field Demonstration)	Groundwater	BTEX/TPH, Metals	1997	1998
Commencement Bay, South Tacoma Channel Well 12A Superfund Site, WA	Pump and Treat with GAC	Groundwater	Chlorinated Solvents	1988	1995
Des Moines TCE Superfund Site, OU 1, IA	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1987	1998
Former Firestone Facility Superfund Site, CA	Pump and Treat with Air Stripping, GAC, and Oil/Water Separation	Groundwater	Chlorinated Solvents	1986	1998

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Ft. Drum, Fuel Dispensing Area 1595, NY	Pump and Treat with Air Stripping and GAC	Groundwater	BTEX/TPH	1992	1995
Fort Lewis Logistics Center, WA	Pump and Treat	Groundwater	Chlorinated Solvents	1995	2000
JMT Facility RCRA Site (formerly Black & Decker RCRA Site), NY	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1988	1998
Keefe Environmental Services Superfund Site, NH	Pump and Treat with Air Stripping and Coagulation/Flocculation	Groundwater	Chlorinated Solvents	1993	1998
King of Prussia Technical Corporation Superfund Site, NJ	Pump and Treat with Air Stripping, GAC, and Electrochemical Treatment	Groundwater	Chlorinated Solvents, BTEX/TPH, Metals	1995	1998
Langley Air Force Base, IRP Site 4, VA	Pump and Treat with Air Stripping	Groundwater	BTEX/TPH	1992	1995
LaSalle Electrical Superfund Site, IL	Pump and Treat with Air Stripping, GAC, and Oil/Water Separation	Groundwater	Chlorinated Solvents, PCBs	1992	1998
Lawrence Livermore National Laboratory (LLNL) Site 300 - General Services Area (GSA) Operable Unit, CA	Pump and Treat with Air Stripping and GAC; SVE	Groundwater	Chlorinated Solvents	1991	1998
Marine Corps Base, OU 1 and 2, Camp Lejeune, NC	Pump and Treat	Groundwater	Chlorinated Solvents, BTEX, Metals	1995	2001
Marine Corps Base, Campbell Street Fuel Farm, Camp Lejeune, NC	Pump and Treat	Groundwater	BTEX, Pesticide/Herbicide (Ethylene dibromide)	1996	2001
McClellan Air Force Base, Operable Unit B/C, CA	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1988	1995
Mid-South Wood Products Superfund Site, AR	Pump and Treat with GAC, Filtration, and Oil/Water Separation	Groundwater	PAHs, Metals	1989	1998
Mystery Bridge at Hwy 20 Superfund Site, Dow/DSI Facility - Volatile Halogenated Organic (VHO) Plume, WY	Pump and Treat with Air Stripping; SVE	Groundwater	Chlorinated Solvents	1994	1998
Naval Air Station, Brunswick, Eastern Groundwater Plume, ME	Pump and Treat	Groundwater	Chlorinated Solvents	1995	2001

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Odessa Chromium I Superfund Site, OU 2, TX	Pump and Treat with Chemical Treatment and Filtration	Groundwater	Metals	1993	1998
Odessa Chromium IIS Superfund Site, OU 2, TX	Pump and Treat with Chemical Treatment and Filtration	Groundwater	Metals	1993	1998
Offutt AFB, Site LF-12, NE	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1997	1998
Old Mill Superfund Site, OH	Pump and Treat with Air Stripping and GAC	Groundwater	Chlorinated Solvents	1989	1998
Ott/Story/Cordova Superfund Site, North Muskegon, MI	Pump and Treat	Groundwater	Chlorinated Solvents, Non-chlorinated VOCs, PCBs, Pesticides, Metals	1996	2001
Pope AFB, Site FT-01, NC	Free Product Recovery	Groundwater	BTEX/TPH	1993	1998
Pope AFB, Site SS-07, Blue Ramp Spill Site, NC	Free Product Recovery	Groundwater	BTEX/TPH	1993	1998
SCRDI Dixiana Superfund Site, SC	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1992	1998
Shaw AFB, Site OT-16B, SC	Hydraulic Containment Through Pumping	Groundwater	Chlorinated Solvents	1995	1998
Shaw AFB, Sites SD-29 and ST-30, SC	Free Product Recovery with Air Stripping	Groundwater	Chlorinated Solvents, BTEX/TPH	1995	1998
Solid State Circuits Superfund Site, MO	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1993	1998
Sol Lynn/Industrial Transformers Superfund Site, TX	Pump and Treat with Air Stripping, GAC, and Filtration	Groundwater	Chlorinated Solvents	1993	1998
Solvent Recovery Services of New England, Inc. Superfund Site, CT	Pump and Treat with GAC, Chemical Treatment, Filtration, and UV/Oxidation; Vertical Barrier Wall	Groundwater	Chlorinated Solvents, Metals	1995	1998
Sylvester/Gilson Road Superfund Site, NH	Pump and Treat with Air Stripping, Biological Treatment, Chemical Treatment, and Filtration; Cap; SVE; Vertical Barrier Wall	Groundwater	Chlorinated Solvents, Metals	1982	1998
Twin Cities Army Ammunition Plant, MN	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1987	1995

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
United Chrome Superfund Site, OR	Pump and Treat with Chemical Treatment	Groundwater	Metals	1988	1998
U.S. Aviex Superfund Site, MI	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents, Diethyl Ether	1993	1998
U.S. Department of Energy Kansas City Plant, MO	Pump and Treat with Advanced Oxidation Processes	Groundwater	Chlorinated Solvents	1983	1995
U.S. Department of Energy Savannah River Site, A/M Area, SC	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1985	1995
Western Processing Superfund Site, WA	Pump and Treat with Air Stripping and Filtration	Groundwater	Chlorinated Solvents, PAHs, Metals	1988	1998
***In Situ* Groundwater Bioremediation (28 Projects)**					
Abandoned Manufacturing Facility - Emeryville, CA	Bioremediation	Groundwater	Chlorinated Solvents, Metals	1997	2000
Avco Lycoming Superfund Site, PA	Bioremediation	Groundwater	Chlorinated Solvents, Metals	1997	2000
Balfour Road Site, CA; Fourth Plain Service Station Site, WA; Steve’s Standard and Golden Belt 66 Site, KS	Bioremediation	Groundwater	BTEX/TPH	1995	1998
Brownfield Site, Chattanooga, TN (specific site name not identified)	Bioremediation	Soil and Groundwater	MTBE, BTEX/TPH	1999	2001
Contemporary Cleaners, Orlando. FL	Bioremediation (HRC)	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Cordray's Grocery, Ravenel, SC	Bioremediation (ORC)	Soil and Groundwater	MTBE, BTEX, PAHs	1998	2001
Dover Air Force Base, Area 6, DE	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2000
Edwards Air Force Base, CA	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2000
French Ltd. Superfund Site, TX	Bioremediation; Pump and Treat with Activated Sludge	Groundwater	Chlorinated Solvents	1992	1998
Gas Station, Cheshire, CT (specific site name not identified)	Bioremediation	Groundwater	MTBE, BTEX/TPH	1997	2001

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Hanford Site, WA	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1995	2000
Hayden Island Cleaners, Portland, OR	Bioremediation (HRC)	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Lawrence Livermore National Laboratory, CA	Bioremediation (Bench Scale)	Groundwater	MTBE	Not Provided	2001
Libby Groundwater Superfund Site, MT	Bioremediation; Pump and Treat	Groundwater	PAHs	1991	1998
Moffett Field Superfund Site, CA	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1986	2000
Naval Weapons Station Seal Beach, CA	Bioremediation (Field Demonstration)	Groundwater	BTEX/TPH	1997	2000
Pinellas Northeast Site, FL	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1997	1998
Savannah River Site, SC	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1992	2000
Service Station, CA (specific site name not identified)	Bioremediation (ORC)	Groundwater	MTBE, BTEX	Not Provided	2001
Service Station, Lake Geneva, WI (specific site name not identified)	Bioremediation (ORC)	Groundwater	MTBE, BTEX	Not Provided	2001
Site A (actual name confidential), NY	Bioremediation; Air Sparging; SVE; Pump and Treat with Air Stripping	Groundwater	BTEX/TPH	1995	1998
South Beach Marine, Hilton Head, SC	Bioremediation	Groundwater	MTBE, BTEX, PAHs	1999	2001
Specific site name not identified	Bioremediation (Bench Scale)	Soil and Groundwater	MTBE	Not Provided	2001
Texas Gulf Coast Site, TX	Bioremediation	Groundwater	Chlorinated Solvents	1995	2000
U.S. Department of Energy Savannah River Site, M Area, SC	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1992	1997
U.S. Navy Construction Battalion Center, Port Hueneme, CA	Bioremediation (Field Demonstration)	Groundwater	MTBE, Volatiles-Nonhalogenated	1998	2001
Vandenberg Air Force Base, Lompoc, CA	Bioremediation (Field Demonstration)	Groundwater	MTBE	1999	2001
Watertown Site, MA	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2000

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Other *In Situ* Groundwater Treatment (45 Projects)					
328 Site, CA	Multi-Phase Extraction	Groundwater	Chlorinated Solvents	1996	2000
Amcor Precast, UT	Air Sparging	Groundwater	BTEX/TPH	1992	1995
Butler Cleaners, Jacksonville, FL	Chemical Oxidation ($KMnO_4$)	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Camp Lejeune Marine Corps Base, Bldg 25, Camp Lejeune, NC	*In Situ* Flushing (SEAR and PITT)	Groundwater	Chlorinated Solvents - PCE	1999	2001
Confidential Manufacturing Facility, IL	Six Phase Heating	Groundwater	Chlorinated Solvents	1998	2000
Defense Supply Center, Acid Neutralization Pit, VA	Multi-Phase Extraction (Field Demonstration)	Groundwater	Chlorinated Solvents	1997	2000
Eaddy Brothers, Hemingway, SC	Air Sparging/SVE	Soil and Groundwater	MTBE, BTEX, PAHs	1999	2001
Eight Service Stations, MD (specific sites not identified)	Multi-Phase Extraction	Soil and Groundwater	MTBE, BTEX	1990	2001
Fernald Environmental Management Project, OH	*In Situ* Flushing (Field Demonstration)	Groundwater	Metals (Uranium)	1998	2001
Former Intersil, Inc. Site, CA	Permeable Reactive Barrier; Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1995	1998
Former Nu Look One Hour Cleaners, Coral Springs, FL	Air Sparging Recirculation Well (NoVOCs^{TM})	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Former Sages Dry Cleaners, Jacksonville, FL	*In Situ* Flushing (Ethanol Co-solvent)	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Fort Devens, AOCs 43G and 43J, MA	Monitored Natural Attenuation	Groundwater	BTEX/TPH	1997	2000
Four Service Stations (specific site names not identified)	Air Sparging	Groundwater	MTBE, BTEX	1993	2001
Fry Canyon, UT	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Metals, Radionuclides	1997	2000
Gold Coast Superfund Site, FL	Air Sparging; Pump and Treat	Groundwater	Chlorinated Solvents	1994	1998

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Hanford Site, 100-H and 100-D Areas, WA	Chemical Reduction/Oxidation (Field Demonstration)	Groundwater	Metals	1995	2000
Johannsen Cleaners, Lebanon, OR	Multi-Phase Extraction	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Keesler Air Force Base Service Station, AOC-A (ST-06), MS	Monitored Natural Attenuation	Groundwater	BTEX/TPH, Metals	1997	2000
Kelly Air Force Base, Former Building 2093 Gas Station, TX	Monitored Natural Attenuation	Groundwater	BTEX/TPH	1997	2000
Lawrence Livermore National Laboratory Gasoline Spill Site, CA	Dynamic Underground Stripping (Field Demonstration)	Groundwater	BTEX/TPH	1992	1995
Louisiana Army Ammunition Plant, LA	Monitored Natural Attenuation	Groundwater	Explosives	Not Provided	2001
Miamisburg, OH	Air Sparging/Soil Vapor Extraction	Soil and Groundwater	Chlorinated Solvents	1997	2001
Milan Army Ammunition Plant, TN	Constructed Wetlands (Field Demonstration)	Groundwater	Explosives/Propellants	1996	2000
Moffett Federal Airfield, CA	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	1998
Moffett Field Superfund Site, CA	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2000
Monticello Mill Tailings Site, Monticello, UT	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Metals	1999	2001
Multiple Air Force Sites	Monitored Natural Attenuation (Field Demonstration)	Groundwater	Chlorinated Solvents	1993	2001
Multiple Air Force Sites	Monitored Natural Attenuation (Field Demonstration)	Groundwater	TPH	1993	2001
Multiple Air Force Sites	Bioslurping (Field Demonstration)	Groundwater	TPH	Not Provided	2001
Naval Air Station, Pensacola, FL	*In Situ* Oxidation; Monitored Natural Attenuation	Groundwater	Chlorinated Solvents	1998	2001

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Naval Air Station Pensacola, OU 10, FL	*In Situ* Oxidation; Fenton's Reagent (Field Demonstration)	Groundwater	Chlorinated Solvents	1998	2000
Naval Submarine Base Kings Bay, GA	*In Situ* Oxidation; Fenton's Reagent	Groundwater	Chlorinated Solvents	1998	2000
Naval Submarine Base, Kings Bay, GA	*In Situ* Oxidation; Monitored Natural Attenuation	Groundwater	Chlorinated Solvents	1999	2001
Pinellas Northeast Site, FL	Air Sparging - Dual Auger Rotary Steam Stripping (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	1998
Pinellas Northeast Site, FL	Membrane Filtration - PerVap™ (Field Demonstration)	Groundwater	Chlorinated Solvents	1995	1998
Portsmouth Gaseous Diffusion Plant, X-701B Facility, OH	*In Situ* Oxidation (Field Demonstration)	Groundwater	Chlorinated Solvents	1988	2000
Scotchman #94, Florence, SC	Air Sparging; Pump and Treat	Groundwater	MTBE, BTEX, PAHs	1998	2001
South Prudence Bay Island Park, T-Dock Site, Portsmouth, RI	Biosparging	Groundwater	BTEX	1998	2001
Sparks Solvents/Fuel Site, Sparks, NV	Multi-Phase Extraction	Soil and Groundwater	MTBE, Chlorinated Solvents, TPH	1995	2001
Tacony Warehouse, PA	Permeable Reactive Barrier; Pump and Treat	Groundwater	Chlorinated Solvents	1998	2000
Tinkham's Garage Superfund Site, NH	Multi-Phase Extraction	Groundwater	Chlorinated Solvents	1994	2000
U.S. Coast Guard Support Center, NC	Permeable Reactive Barrier	Groundwater	Chlorinated Solvents, Metals	1996	1998
U.S. Department of Energy Savannah River Site, A/M Area, SC	Air Sparging (Field Demonstration)	Groundwater	Chlorinated Solvents	1990	1995
Visalia Superfund Site, CA	Dynamic Underground Stripping (Field Demonstration)	Groundwater	PAHs (Creosote)	1997	2000

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Debris/Solid Media Treatment (24 Projects)					
Alabama Army Ammunition Plant, AL	Transportable Hot-Gas Decontamination (Field Demonstration)	Debris/Solid Media	Explosives	1995	1998
Argonne National Laboratory - East, IL	Physical Separation (Scabbling) (Field Demonstration)	Debris/Solid Media	Radionuclides	Not Provided	2000
Argonne National Laboratory - East, IL	Physical Separation (Concrete Demolition) (Field Demonstration)	Debris/Solid Media	Radionuclides	1997	2000
Argonne National Laboratory - West, Waste Area Group 9, OU 9-04, ID	Solidification/Stabilization (Phosphate Bonded Ceramics) (Field Demonstration)	Debris/Solid Media	Metals	Not Provided	2000
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	Centrifugal Shot Blast (Field Demonstration)	Debris/Solid Media	Radionuclides	1997	1998
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	Rotary Peening with Captive Shot (Field Demonstration)	Debris/Solid Media	Radionuclides	1997	1998
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	Roto Peen Scaler with VAC-PAC^R System (Field Demonstration)	Debris/Solid Media	Radionuclides	1996	1998
Clemson University, SC	Solidification/Stabilization (Sintering) (Bench Scale)	Debris/Solid Media	Metals	1995	2000
Fernald Site, OH	Physical Separation (Soft Media Blasting) (Field Demonstration)	Debris/Solid Media	Radionuclides	1996	2000
Hanford Site, WA	Physical Separation (Concrete Grinder) (Field Demonstration)	Debris/Solid Media	Radionuclides	1997	2000
Hanford Site, WA	Physical Separation (Concrete Shaver) (Field Demonstration)	Debris/Solid Media	Radionuclides	1997	2000
Hanford Site, WA	Physical Separation (Concrete Spaller) (Field Demonstration)	Debris/Solid Media	Radionuclides	1998	2000
Hanford Site, WA	Solidification/Stabilization (Polyester Resins) (Field Demonstration)	Debris/Solid Media	Metals, Radionuclides	Not Provided	2000
Idaho National Engineering and Environmental Laboratory, ID	Solidification/Stabilization (Innovative Grouting and Retrieval)	Debris/Solid Media	Radionuclides	1994	2000

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Idaho National Engineering and Environmental Laboratory, Pit 2, ID	Solidification/Stabilization (Polysiloxane) (Field Demonstration)	Debris/Solid Media	Metals	1997	2000
Idaho National Engineering and Environmental Laboratory, ID	Solidification/Stabilization (DeHg^{SM} Process) (Field Demonstration)	Debris/Solid Media	Metals	1998	2000
Idaho National Engineering and Environmental Laboratory, ID	Vitrification (Graphite Furnace) (Field Demonstration)	Debris/Solid Media	Metals, Radionuclides	1997	2000
Lawrence Livermore National Laboratory, CA	Chemical Reduction/Oxidation; Direct Chemical Oxidation (Field Demonstration)	Debris/Solid Media	Chlorinated Solvents, Explosives/Propellants	Not Provided	2000
Los Alamos National Laboratory, Technical Area 33, NM	Solidification/Stabilization (Field Demonstration)	Debris/Solid Media	Metals, Radionuclides	1997	2000
Los Alamos National Laboratory, NM	Solidification/Stabilization (ADA Process) (Field Demonstration)	Debris/Solid Media	Metals	1998	2000
Pacific Northwest National Laboratory, WA	Solidification/Stabilization (Sol Gel Process) (Bench Scale)	Debris/Solid Media	Metals	Not Provided	2000
Portsmouth Gaseous Diffusion Plant, OH	Solidification/Stabilization (ATG Process) (Field Demonstration)	Debris/Solid Media	Metals, Radionuclides	1998	2000
Savannah River Site, SC	Chemical Reduction/Oxidation (Acid Digestion) (Field Demonstration)	Debris/Solid Media	Radionuclides	1996	2000
STAR Center, ID	Vitrification (Plasma Process) (Field Demonstration)	Debris/Solid Media	Metals, Radionuclides	1993	2000
Containment (5 Projects)					
Dover Air Force Base, Groundwater Remediation Field Laboratory National Test Site, Dover DE	Vertical Engineered Barrier (Field Demonstration)	Groundwater	None	1996	2001
Lawrence Livermore National Laboratory (LLNL) Site 300 - Pit 6 Landfill OU, CA	Cap	N/A	Chlorinated Solvents, Radioactivity	1997	1998
Oak Ridge National Laboratory, TN	Frozen Soil Barrier (Field Demonstration)	Groundwater	Radionuclides	1996	2000

EXHIBIT A-1. SUMMARY OF 274 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Sandia National Laboratory, Albuquerque, NM	Cap (Field Demonstration)	N/A	Not contaminated	1995	2001
U.S. Department of Energy, SEG Facilities, TN	Frozen Soil Barrier Technology (Field Demonstration)	Soil (*in situ*)	Not Applicable (not a contaminated site)	1994	1997

* Full scale unless otherwise noted

Key:
DNAPLs = Dense Non-Aqueous Phase Liquids
SVOCs = Semi-Volatile Organic Compounds
GAC = Granular Activated Carbon
SVE = Soil Vapor Extraction
BTEX = Benzene, Toluene, Ethylbenzene, and Xylene
TPH = Total Petroleum Hydrocarbons
PAHs = Polycyclic Aromatic Hydrocarbons
PCBs = Polychlorinated Biphenyls
TCA = 1,1,1-Trichloroethane
TCE = Trichloroethene
PCE = Tetrachloroethene
DCE = Dichloroethene
TNT = 2,4,6-Trinitrotoluene
RDX = Hexahydro-1,3,5-trinitro-1,3,5 triazine
HMX = Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
MBOCA = 4,4-methylene bis(2-chloroaniline)
MIBK = Methyl isobutyl ketone

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