Abstracts of Remediation Case Studies

Volume 7

Federal Remediation Technologies Roundtable
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Prepared by the

Member Agencies of the
Federal Remediation Technologies Roundtable

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Federal Remediation Technologies Roundtable

Environmental Protection Agency
Department of Defense
- U.S. Air Force
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- U.S. Navy

Department of Energy
Department of Interior
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FOREWORD

This report is a collection of abstracts summarizing 29 new case studies of site remediation applications prepared primarily by federal agencies. The case studies, collected under the auspices of the Federal Remediation Technologies Roundtable (Roundtable), were undertaken to document the results and lessons learned from technology applications. They will help establish benchmark data on cost and performance which should lead to greater confidence in the selection and use of cleanup technologies.

The Roundtable was created to exchange information on site remediation technologies, and to consider cooperative efforts that could lead to a greater application of innovative technologies. Roundtable member agencies, including the U.S. Environmental Protection Agency (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 342 remediation technology case studies (the 29 new case studies and 313 previously-published case studies). Appendix A to this report identifies the specific sites, technologies, contaminants, media, and year published for the 342 case studies.

Abstracts, Volume 7, 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.

2003 Series

CD-ROM: FRTR Cost and Performance Case Studies and Related Information, 4th Edition; EPA-542-C-03-002; July 2003

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

Volume 6: EPA-542-R-02-006; June 2002

Volume 7: EPA 542-R-03-011; July 2003

Accessing Case Studies

The case studies and case study abstracts are available on the Internet through the Roundtable web site at: http://www.frtr.gov/costperf.htm. 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, primary and supplemental technology types, site name, and site location. 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 7 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
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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. At this time, the Roundtable is publishing a CD-ROM (4th Edition), which contains a total of 342 remediation technology case studies (29 new case studies and 313 previously-published case studies), primarily focused on contaminated soil and groundwater cleanup.

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

By including a recommended reporting format, the Roundtable is working to standardize the reporting of costs and performance 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.

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; metals; and radioactive materials.

Table 1 provides summary information about the technology used, contaminants and media treated, and project duration for the 29 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).

Appendix A to this report provides a summary of key information about all 342 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	PAHs	Metals	Radionuclides			
***In Situ* Soil Treatment**									
Soil Vapor Extraction (SVE)									
Multiple (6) Drycleaner Sites, Various Locations (SVE)	●	●					Soil and DNAPL	Various dates from November 1992 - Summer 1997	Use of SVE to remediate soil contaminated with chlorinated solvents and BTEX at drycleaning sites
Multiple (3) Drycleaner Sites - SVE/MNA, Various Locations (SVE/Monitored Natural Attenuation)	●						Soil and Groundwater	Various dates from 1996 - April 2002	Use of SVE and MNA to remediate soil and groundwater contaminated with chlorinated solvents at drycleaning sites
Multiple (7) Dry Cleaner Sites - P&T/SVE/MPE, Various Locations (Pump and Treat/SVE/Multi Phase Extraction)	●	●					Soil, Groundwater, DNAPL	Various dates from 1991 - April 2000	Use of SVE, Pump and Treat, and Multi Phase Extraction to remediate soil and groundwater contaminated with chlorinated solvents and BTEX at drycleaning sites
Multiple (3) Drycleaner Sites - SVE/Air Sparging, Various Locations (SVE/Air Sparging)	●						Soil, Groundwater, DNAPL (Plume size range: 52,800 - 57,600 ft^2)	Various dates from Summer 1995 - August 2001	Use of SVE and air sparging to remediate soil and groundwater contaminated with chlorinated solvents at drycleaner sites
***In Situ* Thermal Treatment**									
Avery Dennison, IL (*In Situ* Thermal Treatment - Electrical Resistive Heating)	●						Soil, DNAPL (16,000 yd^3)	December 1999 - November 2000	*In situ* thermal treatment (electrical resistive heating) of soil contaminated with methylene chloride
Confidential Chemical Manufacturing Facility, IN (*In Situ* Thermal Treatment - Conductive Heating)	●						Soil, DNAPL (5,000 yd^3)	July - December 1997	*In situ* thermal treatment (conductive heating) to treat chlorinated solvents in soil
Savannah River Site 321-M Solvent Storage Tank Area, GA (*In Situ* Thermal Treatment - Dynamic Underground Stripping/Hydrous Pyrolysis Oxidation)	●						Soil, Groundwater, DNAPL (52,000 yd^3)	September 2000 - September 2001	Field demonstration of *in situ* thermal treatment (DUS/HPO) to treat soil contaminated with chlorinated solvents

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	PAHs	Metals	Radionuclides			
Other *In Situ* Soil/Sediment Treatment									
Crooksville/Roseville Pottery Area of Concern, OH (CRPAC) (Solidification/stabilization)					●		Soil ($5\ yd^3$)	September 1998 (long-term monitoring is ongoing)	Field demonstration of *in situ* solidification/stabilization to treat soil contaminated with lead from pottery-making processes
Paducah Gaseous Diffusion Plant (PGDP) Superfund Site, KY (Lasagna™)	●						Soil ($6{,}480\ ft^2$ area)	December 1999 - December 2001	Use of Lasagna™ to reduce TCE concentrations in soil to below cleanup levels
Koppers Co. (Charleston Plant) Ashley River Superfund Site, SC (Solidificatiom/Stabilization)				●			Sediment, DNAPL ($2{,}450\ yd^3$)	September - December 2001	Use of solidification/stabilization to treat PAHs and DNAPL in river sediments using innovative construction equipment such as a "tubular injector" and "march excavation"
***Ex Situ* Soil Treatment**									
Thermal Desorption									
Site B (actual site name confidential), Western United States (Thermal Desorption)			●				Soil (26,000 tons)	April - August 1995	Use of thermal desorption to treat soil contaminated with organochlorine pesticides, including DDT
Brookhaven National Laboratory (BNL), NY (Thermal Desorption)					●		Soil (3,050 lbs)	Not provided	Field demonstration using the Sepradyne™-Raduce system for removing and recovering mercury from a mixed waste matrix
Industrial Latex Superfund Site, NJ (Thermal Desorption)			●				Soil ($53{,}685\ yd^3$)	April 1999 - June 2000	Use of thermal desorption to treat soil contaminated with a variety of organic contaminants including pesticides, SVOCs, and PAHs

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	PAHs	Metals	Radionuclides			
***In Situ* Groundwater Treatment**									
Bioremediation									
Altus Air Force Base, Landfill 3 (LF 3), OK (Bioremediation)	●						Groundwater	July 2000 - ongoing	Field demonstration of mulch biowall to treat groundwater contaminated with chlorinated solvents
Offutt Air Force Base, NE (Bioremediation)	●						Groundwater	August 2000 (completion date)	Field demonstration of mulch biowall to treat groundwater contaminated with chlorinated solvents
Naval Weapons Industrial Reserve Plant (NWIRP), TX (Bioremediation)	●						Groundwater	October 1999 - September 2000	Use of *in situ* biotransformation using molasses injection to treat groundwater contaminated with chlorinated solvents
Multiple (4) Dry Cleaner Sites - *In Situ* Bioremediation, Various Locations (Bioremediation)	●	●					Groundwater (Plume size range: 4,375 - 20,000 ft^2)	Various dates from January 2002 - January 2003	Use of *in situ* bioremediation to treat chlorinated solvents in groundwater at drycleaning sites
***In Situ* Thermal Treatment**									
Fort Richardson, AK (*In Situ* Thermal Treatment - Electrical Resistive Heating)	●						Groundwater, Soil, DNAPL	July - October 1999	Field demonstration of *in situ* thermal treatment (electrical resistive heating) to treat groundwater contaminated with chlorinated solvents
A.G. Communication Systems, IL (*In Situ* Thermal Treatment - Steam Enhanced Extraction)	●	●					Groundwater, Soil	September 1995 - November 1999	Use of *in situ* thermal treatment (steam enhanced extraction) in conjunction with SVE to treat groundwater and soil contaminated with chlorinated solvents

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	PAHs	Metals	Radionuclides			
ICN Pharmaceuticals, OR (*In Situ* Thermal Treatment - Electrical Resistive Heating)	●						Groundwater, Soil, DNAPL (Estimated area of plume: 12 ft X 80 ft)	May 2000 - December 2001	Use of *in situ* thermal treatment (electrical resistive heating) in conjunction with SVE to treat soil contaminated with chlorinated solvents, including DNAPL
Cape Canaveral Air Force Station, Launch Complex 34, FL (*In Situ* Thermal Treatment - Electrical Resistive Heating)	●						Soil, Groundwater, DNAPL	August 1999 - July 2000	Field demonstration of *in situ* thermal treatment (electrical resistive heating) using a novel electrode design to treat soil contaminated with halogenated volatile compounds
Air Sparging									
Multiple (10) Sites - Air Sparging, Various Locations (Air Sparging)	●	●					Groundwater, Soil (1,500 yd^3)	Various dates (varied by site)	Multi-site study of *in situ* air sparging to evaluate the Air Sparging Design Paradigm (Environmental Security Technology Certification Program (ESTCP) 2002)
McClellan Air Force Base (AFB), OU A, CA (Air Sparging)	●						Groundwater, Soil (523 yd^3)	May 1999 - November 2000	Field demonstration to compare cometabolic and non-cometabolic air sparging to treat chlorinated solvents in groundwater
Other *In Situ* Groundwater Treatment									
Clear Creek/Central City Superfund site, CO (Constructed Wetlands System)					●		Groundwater (mine drainage)	Fall 1994 - Fall 1997	Field demonstration of constructed wetlands to treat zinc in acid mine drainage
Marshall Space Flight Center, AL (Chemical Oxidation/Reduction (*in situ*))	●						Groundwater	July 2000 - ongoing	Field demonstration of *in situ* chemical reduction to treat groundwater contaminated with chlorinated solvents at a site containing UXO

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	PAHs	Metals	Radionuclides			
Multiple (2) Dry Cleaner Sites - *In Situ* Chemical Oxidation, Various Locations (Chemical Oxidation/Reduction (*in situ*))	●						Groundwater, DNAPL (Plume size range: 300,000 - 12,000,000 ft^2) One site - 157,500 - 202,500 ft^3 (actual treatment volume)	Various dates from August 1998 - April 2002	Use of *in situ* chemical oxidation to remediate groundwater contaminated with chlorinated solvents at drycleaning sites
Cape Canaveral Air Force Station, Launch Complex 34, FL (Chemical Oxidation/Reduction (*in situ*))	●						Groundwater, DNAPL	September 1999 - April 2000	Field demonstration of *in situ* chemical oxidation to treat groundwater contaminated with chlorinated solvents
Multiple DoD Sites, Various Locations (Permeable Reactive Barrier)	●						Groundwater	Various dates (e.g., Moffett and Seneca ongoing through 2001)	Field demonstration to evaluate long-term performance and hydraulic conductivity of PRBs in different hydrogeologic settings and with varying measurement techniques
***Ex Situ* Groundwater Treatment**									
Paducah Gaseous Diffusion Plant, Kentucky (Pump and Treat)						●	Groundwater (840,000 gallons)	February - September 1999	Field demonstration of a bi-functional resin to treat groundwater contaminated with technetium (^{99}Tc)

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

Table 2. Remediation Case Studies: Summary of Cost Data

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs
***In Situ* Soil Treatment**					
Soil Vapor Extraction (SVE)					
Multiple (6) Drycleaner Sites (SVE)	DI - $18,000 - $52,000 (Cox's Martinizing and Art's Dry Cleaners) AO - $1,750 (Cox's Martinizing)	Not Provided	Not Provided	Not Provided	ABC Cleaners and Wash 'N Dry Cleaners: SVE difficult to implement where bedrock and water table are shallow
Multiple (3) Drycleaner Sites - SVE/MNA (SVE/Monitored Natural Attenuation)	DI - $109,000 - $135,000 AO - $28,000 - $30,000	Not Provided	Not Provided	Not Provided	Dry Clean Inn: Permeable soils in contaminant source area made SVE easy to implement
Multiple (7) Dry Cleaner Sites - P&T/SVE/MPE (Pump and Treat/SVE/Multi Phase Extraction)	DI - $98,385 - $1,690,000	Not Provided	Not Provided	Not Provided	Varsity Cleaners: Pump and treat operation limited to wet season
Multiple (3) Drycleaner Sites - SVE/Air Sparging (SVE/Air Sparging)	DI - Hooker's Cleaners - $251,552	Not Provided	Not Provided	Not Provided	Hooker's Cleaners: Gravel in soil made air sparging difficult to implement
***In Situ* Thermal Treatment**					
Avery Dennison (*In Situ* Thermal Treatment - Electrical Resistive Heating)	Not Provided	16,000 yd^3	Not Provided	Not Provided	Installation of heater/vacuum wells to prevent contaminant migration out of treatment zone and provide heating of entire treatment zone
Confidential Chemical Manufacturing Facility (*In Situ* Thermal Treatment - Conductive Heating)	Not Provided	5,000 yd^3	Not Provided	Not Provided	Additional galvanized steel pipe electrodes with above-ground power cable connections improved power input but resulted in an extension of treatment time
Savannah River Site 321-M Solvent Storage Tank Area (*In Situ* Thermal Treatment - Dynamic Underground Stripping/Hydrous Pyrolysis Oxidation)	Not Provided	52,000 yd^3	Not Provided	$29/$yd^3$	Continuous long-term steam injection to heat shallow portions at center of treatment area. Cost of steam generation and treatment of vapor and dissolved phase contaminants not included in total cost.

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

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs
Other *In Situ* Soil/Sediment Treatment					
Crooksville/Roseville Pottery Area of Concern (CRPAC) (Solidification/stabilization)	Total - $26,000 P - $33,220	5 yd^3	Not Provided	$5,176/$yd^3$	Total volume of soil treated
Paducah Gaseous Diffusion Plant (PGDP) Superfund Site (Lasagna™)	Total - $4,000,000	6,480 ft^2 area	Not Provided	Not Provided	Sampling showed system did not require O&M planned for a third year
Koppers Co. (Charleston Plant) Ashley River Superfund Site	Total - $561,154 (includes equipment and chemical costs, and mobilization/ demobilization)	2,450 yd^3	Not Provided	$229/$yd^3$	Operating time limited to two hours on either side of low tide when excavator was best suited for use
***Ex Situ* Soil Treatment**					
Thermal Desorption					
Site B (actual site name confidential) (Thermal Desorption)	Total: $3,260,517 C - $429,561 AO - $2,830,956	26,000 tons	Not Provided	$125/ton	Stack gas particulate emissions required modifications to the system and performance of a fourth test run
Brookhaven National Laboratory (BNL) (Thermal Desorption)	P - Total -$1,500,000	3,050 lbs	Not Provided	P -$0.90/lb	Increased moisture content of waste increased processing time, electrical costs, and production of wastewater
Industrial Latex Superfund Site (Thermal Desorption)	C and AO - $15,700,000	53,685 yd^3	Not Provided	$292/$yd^3$	Modification of HEPA filter housing to address elevated levels of particulate emissions
***In Situ* Groundwater Treatment**					
Bioremediation					
Altus Air Force Base, Landfill 3 (LF 3) (Bioremediation)	C - $165,000 AO - $51,000 Future AO estimated to be $42,000	Not Provided	Not Provided	Not Provided	Cost for acquiring mulch
Offutt Air Force Base (Bioremediation)	$360/ linear ft to install biowall	Not Provided	Not Provided	Not Provided	Cost for acquiring mulch

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
Naval Weapons Industrial Reserve Plant (NWIRP) (Bioremediation)	Total - $306,557 C - $152,903 AO - $72,560 Other costs - $27,094 (reporting and project management)	Not Provided	Not Provided	Not Provided	Complex hydrogeologic conditions and flat groundwater gradients limited delivery of nutrient solution
Multiple (4) Dry Cleaner Sites - *In Situ* Bioremediation (Bioremediation)	DI - $51,000 - $150,000 AO - Asian Cleaners - $150,000	Plume size range: 4,375 - 20,000 ft^2	Not Provided	Not Provided	Asian Cleaners: Direct push installation of slant biosparge well beneath facility allowed for treatment of primary contaminant source area at site.
***In Situ* Thermal Treatment**					
Fort Richardson (*In Situ* Thermal Treatment - Electrical Resistive Heating)	Not Provided	Not Provided	Not Provided	Not Provided	Not Provided
A.G. Communication Systems (*In Situ* Thermal Treatment - Steam Enhanced Extraction)	Not Provided	Not Provided	Not Provided	Not Provided	Frequency of steam injection cycle
ICN Pharmaceuticals (*In Situ* Thermal Treatment - Electrical Resistive Heating)	Not Provided	Estimated area of plume: 12 ft X 80 ft	Not Provided	Not Provided	System modifications to deal with high temperatures achieved during remediation
Cape Canaveral Air Force Station, Launch Complex 34 (*In Situ* Thermal Treatment - Electrical Resistive Heating)	Total: D - $613,000 (includes $44,000 in waste disposal costs)	Not Provided	Not Provided	Not Provided	Technology reported as cost competitive with life-cycle cost of pump and treat over a 30-year period of comparison
Air Sparging					
Multiple (10) Sites - Air Sparging (Air Sparging	Port Hueneme - Total - $189,880 P - $268,490	1,500 yd^3 P - 1,500 yd^3	Not Provided	$130/$yd^3$ $179/$yd^3$	Area of groundwater contamination; depth to groundwater; depth to base of groundwater contamination; *in situ* heterogeneity; treatment period; and vapor collection and treatment
McClellan Air Force Base (AFB), OU A (Air Sparging)	Total - $891,800 P - $465,500	523 yd^3 P - 2,888 yd^3	Not Provided	$1,705/$yd^3$ P - $161/$yd^3$	Depth to groundwater, size of plume, and operating and monitoring requirements.

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

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs
Other *In Situ* Groundwater Treatment					
Clear Creek/Central City Superfund site (Phytoremediation)	Not Provided	Not Provided	Not Provided	Not Provided	Value of land, proximity of land to contaminant source, climate, and influent volume and chemistry
Marshall Space Flight Center (Chemical Oxidation/Reduction (*in situ*))	Total: $209,900	Not Provided	Not Provided	$19/lb of ZVI injected	Presence of unexploded ordnance (UXO) affected design and operation of demonstration
Multiple (2) Dry Cleaner Sites - *In Situ* Chemical Oxidation (Chemical Oxidation/Reduction (*in situ*))	DI - Ineeda Cleaners - $100,900; Swift Cleaners - $245,000	Swift Cleaners - 157,500 - 202,500 ft^3 (actual treatment volume) Information not provided for Ineeda Cleaners	Not Provided	Not Provided	Ineeda Cleaners: Extensive system maintenance required
Cape Canaveral Air Force Station, Launch Complex 34 (Chemical Oxidation/Reduction (*in situ*))	D - Total: $1,000,000	Not Provided	Not Provided	Not Provided	Technology reported as cost competitive with life-cycle cost of pump and treat over a 30-year period of comparison
Multiple DoD Sites (Permeable Reactive Barrier)	Moffett: Total: $802,375 C - $652,375 AO - $150,000 Dover: Total: $739,000 Pre-construction activities: $365,000 PRB construction: $374,000	Not Provided	Not Provided	Not Provided	Depth of affected aquifer and length of PRB

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
***Ex Situ* Groundwater Treatment**					
Paducah Gaseous Diffusion Plant (Pump and Treat)	BiQuat resin - $1,000/ft^3	840,000 gallons	Not Provided	Not Provided	High cost of BiQuat resin requires large-scale application of the technology to make it commercially viable

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

[2] Cost abbreviation: AO = annual operation and maintenance (O&M) costs, C = capital costs, DI = design and implementation costs, D = Demonstration-scale costs, P = Projected full-scale costs.

IN SITU SOIL TREATMENT ABSTRACTS

Soil Vapor Extraction (SVE) at Six Drycleaner Sites, Various Locations

Site Name:
Multiple (6) Dry Cleaner Sites

Location:
ABC Cleaners, Monroe, MI
Art's Dry Cleaners, Charlevoix, MI
Cox's One Hour Martinizing, Portland, OR
Crain Fabric Care Center, Traverse City, MI
Sunshine Laundry, St. Johns, MI
Wash 'N Dry Cleaners, Spring Arbor, MI

Period of Operation:
ABC Cleaners - March, 1993
Art's Dry Cleaners - October, 1994
Cox One Hour Martinizing - Summer, 1997
Crain Fabric Care Center - November 1992
Sunshine Laundry - Not specified
Wash 'N Dry Cleaners - Not specified

Cleanup Authority:
State

Purpose/Significance of Application:
Use of soil vapor extraction to remediate soil contaminated with chlorinated solvents at drycleaning sites

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents

- Concentrations of PCE in soil varied among the sites and ranged from 0.077 to 1,000 mg/kg. Some of the sites (Wash 'N Dry Cleaners, Art's Dry Cleaners, and ABC Cleaners) reported other chlorinated organics in the soil such as TCE, 1,1,1-TCA, cis-1,2-DCE, methylene chloride, and chloroform.
- 1 site (Art's Dry Cleaners) reported that DNAPLs were present or likely to be present in the soil.
- Concentrations of PCE in groundwater varied among the sites and ranged from 11 µg/L to 550 µg/L. Some of the sites (Art's Dry Cleaners, Wash 'N Dry Cleaners, and Sunshine Laundry), reported other chlorinated organics in groundwater such as TCE, cis 1,2-DCE, trans 1,2-DCE, 1,1,1-TCA, vinyl chloride, chloromethane, methylene chloride, and chloroform.
- Two sites (ABC Cleaners and Crain Fabric Care Center) reported the presence of the nonhalogenated volatiles, benzene and xylenes
- 1 site (Cox's One Hour Martinizing) reported that DNAPLs were present or likely to be present in the groundwater

Waste Source:
Waste and wastewater from drycleaning operations

Contacts:
Varied by site

Technology:
SVE

- At the Cox One Hour Martinizing site, the SVE system consisted of six wells screened at depths ranging from 5 to 40 ft bgs. Two blowers applied a vacuum to wells, and recovered air and vapors were discharged to the atmosphere through a stack extended above the existing dry cleaner building.
- At Art's Dry Cleaners, SVE was implemented with carbon adsorption for vapor treatment.
- No information was provided about the design of the SVE systems at the other sites.

Type/Quantity of Media Treated:
Soil

Soil Vapor Extraction (SVE) at Six Drycleaner Sites, Various Locations (continued)

Regulatory Requirements/Cleanup Goals:
Soil cleanup target levels were not specified for any of the six sites. For two sites (Cox's One Hour Martinizing and Sunshine Laundry), the goal of the cleanup was to remove the contamination mass from the source area and stop contaminant migration.

Results:
- At two sites (ABC Cleaners and Wash 'N Dry Cleaners), SVE failed due to high water levels in the soil
- At Art's Dry Cleaners, PCE concentrations in the soil were reduced from 1,000 to 0.13 mg/kg
- At Cox's One Hour Martinizing, PCE concentrations in the soil were reduced from 25,000 to 5 mg/kg, and approximately 170 gallons of PCE were removed after one year of operation. The concentrations showed a rebounded within the first few months of operation, but decreased afterward. The SVE system removal rate peaked at approximately 12.4 lbs per day within first six months of operation, but later decreased to 0.4 lbs per day.
- No information was provided for the other two sites (Crain Fabric Care Center and Sunshine Laundry).

Costs:
- Design and implementation costs for SVE systems were provided for two sites (Cox's One Hour Martinizing and Art's Dry Cleaners) and ranged from ranged from $18,000 to $52,000
- O&M costs were provided for two sites - Cox's One Hour Martinizing - $3,500 for 2 years, and Crain Fabric - $400 for mobilization and $1,140 per visit for laboratory work.
- Cost information was not provided for the other sites.

Description:
SVE was conducted at six drycleaner sites contaminated with chlorinated organic compounds from drycleaning operations. Cleanup goals for soil were not provided for any of the sites. Two sites reported that SVE reduced PCE concentrations in the soil from 25,000 to 5 mg/kg, and from 1,000 to 130 mg/kg, respectively. At two sites, SVE failed due to high water levels in the soil. No information on the results of SVE at the other two sites. Reported design and implementation costs for the SVE systems ranged from $18,000 to $52,000. O&M costs at one site was $3,500 for a period of 2 years.

Soil Vapor Extraction (SVE) and Monitored Natural Attenuation (MNA) at Three Drycleaner Sites, Various Locations

Site Name:
Multiple (3) Drycleaner Sites - SVE/MNA

Location:
- Aiea Laundry, Naval Station Pearl Harbor, HI
- Dry Clean Inn, Lauderhill, FL
- Former Dollar Cleaners, Lake Worth, FL

Period of Operation:
- Aiea Laundry - 1996 - 1998
- Dry Clean Inn - June, 2000 - June, 2001
- Former Dollar Cleaners - December, 2001 - April, 2002

Cleanup Authority:
State

Purpose/Significance of Application:
Use of SVE and MNA for remediation of chlorinated solvents in soil and groundwater at drycleaner facilities

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents
- Soil contamination consisted of PCE, TCE, cis-1,2-DCE, and vinyl chloride.

Concentrations varied between the sites, ranging from 190 µg/kg to 3,200 µg/kg of PCE
- Groundwater contamination consisted of PCE, TCE, cis-1,2-DCE, trans-1,2-DCE, and vinyl chloride. Concentrations varied between the sites, ranging from 19.9 to 546 µg/L for PCE, 27.4 to 61.9 µg/L for TCE, 63.7 to 127 µg/L for cis-1,2- DCE, 2.6 to 3.81 µg/L for trans-1,2-DCE, and 3.9 µg/L for vinyl chloride.

Waste Source:
Waste and wastewater from drycleaning operations

Contacts:
Varied by site

Technology:
SVE and MNA
- SVE systems varied by site. One site (Dry Clean Inn) used 2 horizontal extraction wells installed beneath the service doors of the facility and the floor slab near the drycleaning machines. A second site (Former Dollar Cleaners) used 6 wells beneath the floor slab of the facility and an adjacent bay in the strip shopping center. The wells applied a vacuum of 14.5 to 64 inches of water and drew 70 to 98.5 scfm soil vapor at depths from 3 to 4 ft bgs.
- At one site, pump and treat of contaminated groundwater was also conducted. The system was designed to recover diesel fuel and prevent further migration of floating product on the groundwater surface. The system continued operation for an unspecified period of time after the SVE system was shut down.
- Natural attenuation was selected for the groundwater remedy for all three sites due to the low contaminant concentrations present in groundwater and the evidence of active reductive dechlorination (PCE degradation products present).

Type/Quantity of Media Treated:
Soil and Groundwater
Groundwater plume areas ranged from 3,200 ft^2 to 8,400 ft^2

Soil Vapor Extraction (SVE) and Monitored Natural Attenuation (MNA) at Three Drycleaner Sites, Various Locations (continued)

Regulatory Requirements/Cleanup Goals:

Soil

- For two sites, cleanup goals were based on state regulatory standards which included 0.03 mg/kg leachable PCE. For the third site, the cleanup goal for soil was the U.S. EPA target risk range (actual values not specified).

Groundwater

- Cleanup goals were based on drinking water MCLs, which was specified for 2 sites as 3.0 µg/L for PCE and TCE, 70 µg/L for cis-1,2-DCE, 100 µg/L for trans-1,2-DCE, and 1.0 µg/L for vinyl chloride.

Results:

- All the sites reported that SVE reduced PCE in soils to below cleanup levels.
- Two sites (Dry Clean Inn and Former Dollar Cleaners) reported that contaminant concentrations in groundwater were below cleanup target levels in the last two monitoring events. Both sites received Site Rehabilitation Completion Orders. No information was provided on the results of MNA at the third site.

Costs:

Design and implementation costs for SVE systems ranged from $109,000 to $135,000, and annual O&M costs for SVE systems ranged from $28,000 to $30,000.

Description:

SVE and MNA was conducted at three drycleaner sites contaminated with chlorinated solvents from leaks, spills, or dumping of drycleaning solvents or wastewaters. All three sites reported that SVE reduced PCE concentrations in soil to below cleanup levels. Two sites reported that contaminant concentrations in groundwater had been reduced by MNA to below cleanup levels in the last two monitoring events. Both sites received Site Rehabilitation Completion Orders. Information on groundwater contaminant concentrations for the third site was not provided. Reported design and maintenance costs for SVE ranged from $109,00 to $135,000. Reported O&M costs for SVE systems ranged from $28,000 to $30,000.

Pump and Treat, Pump and Treat/Soil Vapor Extraction, or Multi-Phase Extraction At Seven Drycleaner Sites, Various Locations

<table>
<tr>
<td>Site Name:
Multiple (7) Dry Cleaner Sites - P&T/SVE/MPE</td>
<td>Location:
• Clotheshanger Cleaners (former), Tallahassee, FL
• Colonial Cleaners, Tompkins County, NY
• Former Norge’s Cleaners, Hays, KS
• Roxy Cleaners, North Greenbush, NY
• Sparta Laundry Basket, Sparta, MI
• Stanton Cleaners Area Groundwater Contamination Site, Great Neck, NY
• Varsity Cleaners, Temple Terrace, FL</td>
</tr>
<tr>
<td>Period of Operation:
• Clotheshanger Cleaners - April, 2000 (pilot test conducted in February, 2001)
• Colonial Cleaners - P&T - June, 1998
• Former Norge’s Cleaners - SVE - 1997; DPE - 1999
• Roxy Cleaners - Not specified
• Sparta Laundry Basket - June, 1991 to December, 1995
• Stanton Cleaners Area Groundwater Contamination Site - 1998
• Varsity Cleaners - SVE - September to November, 1998; P&T - November, 1999</td>
<td>Cleanup Authority:
State</td>
</tr>
<tr>
<td>Purpose/Significance of Application:
Use of multi-phase extraction, pump and treat, and/or SVE to cleanup soil and groundwater contaminated with chlorinated solvents from drycleaning operations.</td>
<td>Cleanup Type:
Full scale</td>
</tr>
<tr>
<td>Contaminants:
Groundwater
Chlorinated Solvents
• All seven sites contaminated with PCE and TCE. Concentrations ranged from 3,500 to 13,000 µg/L for PCE, and from 15 to 120 µg/L for TCE.
• Other chlorinated solvents present at some of the sites were cis-1,2-DCE, vinyl chloride, and 1,1,1-TCA
• Four out of the seven sites reported that DNAPLs were present or likely to be present. These were Clotheshanger Cleaners, Varsity Cleaners, Sparta Laundry Basket, and Former Norge’s Cleaners.
• One site (Varsity Cleaners) also reported the presence of BTEX.
Soil
Chlorinated Solvents
• No information was provided on contaminants in the soil at Sparta Laundry Basket.
• The other six sites were contaminated with PCE, ranging in concentration from 4.3 to 40,000 µg/kg
• Other chlorinated solvents present at some of the sites were TCE and cis-1,2-DCE</td>
<td>Waste Source:
Waste and wastewater from drycleaning operations</td>
</tr>
</table>

Pump and Treat, Pump and Treat/Soil Vapor Extraction, or Multi-Phase Extraction At Seven Drycleaner Sites, Various Locations (continued)

Contacts:
Varied by site

Technology:
Multi-phase extraction:

- Multi-phase extraction was applied at Clotheshanger Cleaners and Former Norge's Cleaners.
- At Clotheshanger Cleaners, the treatment system consisted of eleven 4-inch diameter recovery wells and one 2-inch diameter recovery well, installed to depths of 10 to 60 ft bgs. The extracted soil vapors were treated using two 2,000-lb granular activated carbon adsorbers, and the groundwater was treated using a low-profile air stripper.
- At Former Norge's Cleaners, a DPE system was installed in addition to an existing SVE system. It consisted of four groundwater extraction/SVE wells in conjunction with two of the four existing SVE wells. The groundwater extraction well design pumping rate was 5 gpm, and the extracted groundwater was treated using a shallow tray air-stripper system. The tray stripper was designed to reduce 3,000 µg/L influent PCE concentrations to less than 3 µg/L effluent concentrations.

SVE/Pump and Treat:

- SVE/Pump and Treat was applied at Colonial Cleaners, Varsity Cleaners, Stanton Cleaners, and Roxy Cleaners.
- At Colonial Cleaners and Varsity Cleaners, *ex situ* SVE was performed. No information was provided on the design of the system at Colonial Cleaners. At Varsity Cleaners, 1,750 cy of soil contaminated with PCE were treated using SVE. The recovered leachate was treated using air strippers and then discharged to an exfiltration gallery. The pump and treat system was only operated during the wet season. Extracted water was treated using two 200-lb granular activated carbon filters.
- No information was provided on the design of the system at Stanton Cleaners.
- At Roxy Cleaners, the SVE system was installed to remediate the on-site source of contamination in the vadose zone. The pump and treat system was designed with three groundwater extraction wells consisting of two on site wells in the source area to exert hydraulic control, and one off site well in the overburden to reduce mass and control groundwater migration.

Pump and Treat

- Pump and Treat was applied at Sparta Laundry Basket. The system treated extracted groundwater using granular activated carbon. The water was then discharged to a nearby creek.

Type/Quantity of Media Treated:
Groundwater and Soil

Pump and Treat, Pump and Treat/Soil Vapor Extraction, or Multi-Phase Extraction At Seven Drycleaner Sites, Various Locations (continued)

Regulatory Requirements/Cleanup Goals:

Groundwater

- At four sites, the reported cleanup goals were the drinking water MCL for PCE or TCE. This was less than 0.003 mg/L for Clotheshanger Cleaners and Varsity Cleaners, and less than 0.005 mg/L at Sparta Laundry Basket and Former Norge's Cleaners.
- At two sites (Clotheshanger Cleaners and Varsity Cleaners), the cleanup goal for DCE was the drinking water MCL (0.07 mg/L).
- At Colonial Cleaners, the cleanup goal for PCE was 5 µg/L.

Soil

- At Clotheshanger Cleaners, the cleanup goal was a PCE leachability based on Cleanup Target Levels (CTLs) (0.3 µg/kg).
- At Former Norge's Cleaners, the cleanup goal for PCE was a Kansas Department of Health and Environment (KDHE) RSK level of 180 µg/kg.
- At Colonial Cleaners and Stanton Cleaners, the cleanup goal for soil was 1.4 mg/kg and 1.4 µg/kg, respectively
- At Varsity Cleaners, the cleanup goals were a PCE, TCE, and cis-1,2-DCE leachability standard of 30, 30, and 40 µg/kg, respectively.

Results:

Groundwater

- At Clotheshanger Cleaners, the MPE system pumped a total of approximately 26,000 gallons of water. The system influent for groundwater at startup was 1,430 µg/L PCE. During the latest quarterly sampling event in January 2003, the MPE groundwater influent was 210 µg/L PCE; groundwater concentrations in 3 wells were not substantially changed over 2 years of operation.
- At Colonial Cleaners, PCE, TCE, and 1,2-DCE concentrations 22 months after system startup were 98 µg/L, <3 µg/L, and 23 µg/L, respectively. These concentrations indicate that the goal for TCE was met, but not for PCE or DCE.
- At Varsity Cleaners, the maximum initial influent PCE concentration for the pump and treat system was 0.66 mg/L. During the most recent operation period, the maximum influent PCE concentration was reduced to 0.44 mg/L, indicating that the cleanup goal had not been met.
- At Roxy Cleaners, the pump and treat system reduced levels of contamination by approximately 50% over a period of three years. At the end of this period, the concentrations were still two orders of magnitude above the groundwater standards.
- At Sparta Laundry Basket, the pump and treat system treated approximately 47 million gallons of water. PCE concentrations in water samples collected from one monitoring well dropped from 2.3 mg/L to 0.18 mg/L; TCE concentrations were reduced from 0.023 mg/L to 0.015 mg/L; and 1,1,1-TCA concentrations were reduced from 0.019 mg/L to non-detect. These concentrations indicate that the cleanup goal for 1,1,1-TCA was met, but not the goals for PCE or TCE.
- At Former Norge's Cleaners, there was a 95% reduction of PCE in groundwater monitoring wells downgradient of the remediation system. Some cross-gradient wells remained contaminated at original levels indicating the continued presence of source area contamination. The SVE system removed more than 3,000 lbs of VOCs. The shallow tray air stripper reduced 3,300 µg/L influent concentrations to less than 3 µg/L, removing more than 28 lbs of VOCs from the groundwater run through the tray stripper

Soil

- At Colonial Cleaners, approximately 230 tons of contaminated soil was removed for *ex situ* treatment.
- At Stanton Cleaners, the SVE system removed approximately 16,000 lbs of PCE.
- At Roxy Cleaners, the SVE system reduced vadose zone PCE contamination levels to 0.425 µg/kg, meeting the regulatory goal.

Pump and Treat, Pump and Treat/Soil Vapor Extraction, or Multi-Phase Extraction At Seven Drycleaner Sites, Various Locations (continued)

Costs:
Reported design and implementation costs:
- Clotheshanger Cleaners - $310,500
- Varsity Cleaners - soil excavation and treatment - $387,300; remedial system design and construction: $111,400
- Stanton Cleaners - $1,300,000 for implementation and operation of SVE system
- Roxy Cleaners - $1,690,000
- Former Norge's Cleaners - SVE - $28,550; DPE - $69,835
- Information on cost was not provided for Colonial Cleaners and Sparta Laundry Basket.

Reported O&M costs:
- Clotheshanger Cleaners - $30,000
- Stanton Cleaners - $450,000 for two years; $225,000 for the next 18 years
- Roxy Cleaners - $177,000
- Former Norge's Cleaners - SVE only - $9,573 over a period of 7 months; DPE - $45,250 over a period of 38 months.

Description:
Multi-phase extraction was conducted at two drycleaner sites, SVE/pump and treat at four drycleaner sites, and pump and treat only at one drycleaner site to remediate soil and groundwater contaminated with chlorinated solvents. The amount of contaminant removed from the subsurface varied by site, with as much as 16,000 pounds of PCE removed from the soil at Stanton Cleaners.

Soil Vapor Extraction (SVE) and Air Sparging at Three Drycleaner Sites, Various Locations

Site Name:
Multiple (3) Drycleaner Sites - SVE/Air Sparging

Location:
- Hooker's Cleaners, Charlevoix, MI
- Sunny Village Cleaners, Livonia, MI
- Vicksburg Laundry & Dry Cleaners, Vicksburg, MI

Period of Operation:
- Hooker's Cleaners - August 23, 2001 - not specified (data available as of May 15, 2002)
- Sunny Village Cleaners - February, 1999 - not specified (data available as of May, 2001)
- Vicksburg Cleaners - Summer, 1995 - November, 1997

Cleanup Authority:
State

Purpose/Significance of Application:
Remediation of chlorinated solvents in soil and groundwater at drycleaner facilities using SVE and air sparging

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents - PCE and TCE
- Soil concentrations varied between the sites, ranging from 2,000 µg/kg to 2,131,000 µg/kg for PCE and 23 µg/kg to 9,574 µg/kg for TCE
- Groundwater concentrations varied between the sites, ranging from 1,290 µg/L to 27,824 µg/L for PCE and 248 to 260 µg/L for TCE
- One site reported that DNAPLs were present

Waste Source:
Waste and wastewater from drycleaning operations

Contacts:
Varied by site

Technology:
SVE and Air Sparging
- SVE and air sparging design was provided for one site - Sunny Village Cleaners. The SVE system consisted of 24 wells, with a radius of influence estimated from the pilot test to be 45 ft. The air sparging system consisted of 112 wells.

Type/Quantity of Media Treated:
Soil and Groundwater
Groundwater plume areas ranged from 52,800 ft^2 to 57,600 ft^2

Regulatory Requirements/Cleanup Goals:
Soil
- Cleanup goals for soil were not identified

Groundwater
- Cleanup goals were based on state regulatory cleanup levels and ranged from 5.0 µg/L to 34 µg/L for PCE; the cleanup goal for TCE was 5.0 µg/L

Results:
Soil
- At Sunny Village Cleaners, 284.4 lbs of PCE had been recovered from the soil as of May, 2001

Groundwater
- Hooker's Cleaners: the highest PCE concentration as of May 15, 2002 was 62 µg/L, thereby not meeting the cleanup goal. The system was scheduled to continue operation and then be turned off in late September, 2002, pending results of sampling at that time.
- Sunny Village Cleaners: 34.7 lbs of PCE had been extracted from the groundwater as of May 2001. No information was provided on the resulting concentration of PCE in the groundwater.
- Vicksburg Cleaners: Contamination in a portion of the site was reduced to acceptable drinking water cleanup criteria of 5.0 µg/L for PCE and TCE.

Soil Vapor Extraction (SVE) and Air Sparging at Three Drycleaner Sites, Various Locations (continued)

Costs:
A design and implementation cost of $251,552 was provided for Hooker's Cleaners. Cost information was not provided for the other two sites.

Description:
SVE and air sparging were conducted at three drycleaner sites in Michigan contaminated with chlorinated organic compounds from leaks, spills, or dumping of drycleaning solvents or wastewaters. Cleanup goals for groundwater were based on state regulatory cleanup level, and ranged from 5.0 µg/L to 34 µg/L for PCE. The cleanup goal for TCE was 5.0 µg/L. Although all of the treatment systems removed contaminants from the subsurface, only one treatment reported to have achieved treatment goals for groundwater in a portion of the site.

Electrical Resistive Heating at the Avery Dennison Site, Waukegan, Illinois

Site Name:
Avery Dennison

Location:
Waukegan, Illinois

Period of Operation:
December 1999 to November 2000

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Use of ERH to treat a methylene chloride source zone

Cleanup Type:
Full scale

Contaminants:
Chlorinated solvents
- Methylene chloride

Waste Source:
Leaking underground transfer pipe and storage areas used for methylene chloride

Contacts:

Technology System Vendor:
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Current Environmental Solutions
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State Regulator:
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Division of Remediation Management
Remedial Project Management Section
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Springfield, IL 62794-9276
Telephone: (217)785-9399
Email: Jennifer.Seul@epa.state.il.us

Technology:
Electrical Resistive Heating (ERH)
- 20 treatment cells; electrodes were installed around the perimeter of each cell to a depth of 24 feet; 2 thermocouples were installed in the center of each treatment cell, at the shallowest and deepest levels of contamination, 4 and 24 feet bgs.
- Total of 95 copper electrodes, including six installed below an active street and 16 installed inside the existing building; designed power input - 610 kW ; design heating rate of 1 ^{o}C per day until a temperature above 75 ^{o}C was achieved
- 34 recovery wells at 20 locations to extract of soil vapor and steam
- After four weeks of operation, the average soil temperature, heating rate, and input to the subsurface were below design targets; vendor determined that the copper electrodes had oxidized and down hole power cables to the electrodes were damaged
- 1-inch galvanized steel pipes were installed around each electrode; the power cables were attached above ground
- Maximum temperature - 65^{o}C to 100^{o}C; average delivery of power to the subsurface was 320 kW, less than the expected delivery of 610kW

Type/Quantity of Media Treated:
Source zone- 16,000 yds^3 (based on an estimated soil density of 1.3 tons per yd^3, corresponds to 21,000 tons treated)

Regulatory Requirements/Cleanup Goals:
- MeCl in the soil below 24 mg/kg, based on Illinois EPA's Tiered Approach to Corrective Action Objectives (TACO)

Results:
- Results of soil samples taken from the treatment cells indicated that, with the exception of four treatment cells, concentrations of MeCl had been reduced to below the treatment goals by October 2000
- Additional galvanized steel pipe electrodes were added to the four treatment cells, and the treatment system was operated in these cells for another month, with shut down in November, 2000
- Average MeCl concentrations in soil were reduced to 2.51 mg/kg

Costs:
No cost information was provided for this application

Electrical Resistive Heating at the Avery Dennison Site, Waukegan, Illinois (continued)

Description:
The Avery Dennison site is located in the Waukegan-Gurnee Industrial Park in Waukegan, Illinois. From 1975 through 1992 film coating operations were performed at the site. Methylene chloride (MeCl) used in these operations was unloaded in the northeast corner of the building, and transferred by underground piping to above-ground storage tanks in the northwest corner of the building. In May 1985, an inventory check indicated that approximately 1,585 gallons of MeCl was released from the underground pipe. Site investigations indicated that the released MeCl was present in the soil and groundwater beneath the loading area, the bulk storage tank area, the underground transfer pipe, and a former stormwater drainage system. Cleanup activities at the site performed from 1985 through 1998 included excavation, soil vapor extraction, groundwater pump and treat, and air sparging. The results of additional investigations indicated that DNAPL was present in soil at the site. ERH was used from December 1999 through November 2000 to address the DNAPL source in the unsaturated zone.

The ERH system included 95 copper electrodes installed around the perimeter of 20 treatment cells, including six electrodes installed below an active street, and sixteen installed inside the existing building. Thirty four recovery wells were installed to extract of soil vapor and steam. Two thermocouples were installed in the center of each treatment cell, at the shallowest (4 ft) and deepest (24 ft) levels of contamination. ERH was performed in the western portion of the treatment zone starting in December 1999 and in the eastern portion of the treatment zone starting in June 2000. During the first four weeks of operation, the system did not achieve the target heating rate and power input to the subsurface. The vendor found that the electrodes had oxidized and that the down hole power cables had been damaged. System modifications included installing galvanized steel pipes around the electrodes and using above-ground power cables. The system was restarted and achieved the target heating rate and soil temperature, though the power input remained below the design level. With the exception of four treatment cells, the concentrations of methylene chloride were reduced to below cleanup goals by October 2000. Additional electrodes were added to these cells and the system was operated another month to meet the cleanup goals. No cost data were available for this application.

In Situ Conductive Heating at a Confidential Chemical Manufacturing Facility, Portland, Indiana

Site Name:
Confidential Chemical Manufacturing Facility

Location:
Portland, Indiana

Period of Operation:
July to December 1997

Cleanup Authority:
State voluntary cleanup program

Purpose/Significance of Application:
Use of *in situ* conductive heating to treat VOCs, including DNAPL, in an unsaturated source zone

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents
- Trichloroethene (TCE) - up to 79 mg/kg; tetrachloroethene (PCE)- up to 3,500 mg/kg; 1,1-dichloroethene (DCE) - up to 0.65 mg/kg
- The high concentration of PCE suggested the presence of DNAPL

Waste Source:
Leaks and spills from manufacturing operations

Contacts:

Technology System Vendor:
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TerraTherm, Inc.
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State Regulator:
Mary Beth Tuohy
Assistant Commissioner
Indiana Department of Environmental Management
Office of Environmental Response
P.O. Box 6015
Indianapolis, IN 46206

Technology:
In situ conductive heating
- Three free-standing trailers - a control trailer containing instrumentation, an electrical substation providing power for the system (1 to 1.5 MW), and an off gas vapor treatment trailer containing a flameless thermal oxidizer
- Heater/vacuum wells (4.5 inches in diameter with sand packed liners in 6 inch augured holes) were operated at 1,400 - 1,600 °F; heat was injected into the subsurface with soil gas extracted using a vacuum
- Two areas treated - Area GP-31 (150 ft by 50 ft to a depth of 18 ft); Area GP-28 (30 ft by 20 ft to a depth of 11 ft); Area GP-31-130 heater/vacuum wells installed on 7.5 foot triangular spacing to a depth of 19 feet,with 25 of these wells drilled through the concrete loading dock; Area GP-28 - 18 heater/vacuum wells installed on 7.5 foot triangular spacing to depths of 12 feet, with approximately 1 well per 50 square feet of surface area treated
- Surface area between wells was covered by an impermeable silicone rubber sheet to prevent fugitive emissions; thermally insulated mat was used to minimize surface heat loss; 5 ft deep dewatering trench was installed
- Maximum soil temperature in the treatment area at a depth of 13 ft - 212°F to 500°F
- During operation, recharge of water in the wet till region prevented temperatures in this area from rising above 212°F; however, all temperatures in the area were at least as high as the boiling of water
- Off-gases were treated with an 1800 scfm flameless thermal oxidizer with an operating temperature range of 1800 - 1900ºF

Type/Quantity of Media Treated:
Source zone (unsaturated)
- Estimated area treated was 5,000 cubic yards or 6,500 tons of soil

Regulatory Requirements/Cleanup Goals:
- The soil cleanup goals were 8 mg/kg for PCE, 25 mg/kg for TCE, and 0.080 mg/kg for 1,1-DCE
- Cleanup goals were based on the Indiana Department of Environmental Management (IDEM) Tier II Clean-Up Goals for Industrial Land Use

In Situ Conductive Heating at a Confidential Chemical Manufacturing Facility, Portland, Indiana (continued)

Results:

- Results of confirmatory sampling showed that concentrations of PCE and TCE in both areas were reduced to below the cleanup goals; no data were provided for DCE
- Prior to discontinuing heating, 50 soil samples were collected from the coldest locations (centroids) furthest from each heater well and analyzed for VOCs; based on these results, along with data from temperature profiles and HCl monitoring, heating was discontinued in December 1997
- Confirmation sampling was conducted about six months later, after soil temperatures within the treatment area had cooled to below 100°F.

Costs:

No cost data was provided for this application.

Description:

The 16 acre site is a chemical manufacturing facility located in the southern portion of Portland, Indiana, From 1937 to the mid-1970's, the site was used for the manufacture of hard rubber products used in automobiles and then for the manufacture of plastic exterior automobile parts and is currently being used for reworking automotive parts. Sampling showed the presence of volatile organic compounds (VOCs) in in subsurface soils in two areas at the site that had been used as loading docks. Area GP-31 was contaminated primarily with PCE and TCE; Area GP-28 was contaminated primarily with DCE. VOCs were not found above the cleanup goals in groundwater.

In situ conductive heating was used from July to December 1997 to treat the unsaturated source zone in these two areas. A total of 130 heater/vacuum wells were installed in the larger area (GP-31) and 18 in the smaller area (GP-28). These wells were used to injected heat into the subsurface (1,400 - 1,600 °F) using the vacuum to extract soil gas. Off-gases were treated with a flameless thermal oxidizer. Prior to discontinuing heating, about 50 soil samples were collected from the coldest locations (centroids) furthest from each heater well and analyzed for VOCs. The results from the soil samples, along with data from temperature profiles and HCl monitoring, were used to determine whether additional heating was required. Based on the results, heating was discontinued in December 1997. Before confirmation sampling was conducted, soil temperatures were monitored for about 6 months as the soil within the treatment area cooled to below 100°F. Results of confirmation sampling showed that PCE and TCE concentrations were below the cleanup goals.

Dynamic Underground Stripping-Hydrous Pyrolysis Oxidation at the Savannah River Site 321-M Solvent Storage Tank Area, Aiken, Georgia

Site Name:
Savannah River Site 321-M Solvent Storage Tank Area

Location:
Aiken, Georgia

Period of Operation:
September 9, 2000 to September 28, 2001

Cleanup Authority:
RCRA

Purpose/Significance of Application:
Field demonstration of DUS/HPO to treat DNAPL contamination in the source zone

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents
- Tetrachloroethene (PCE) and trichloroethene (TCE)
- DNAPL contamination - 90% PCE and 10% TCE

Waste Source:
Spills and leaks from storage areas, sewer lines, and settling basins

Contacts:

Technical Contacts:
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Technology System Vendor:
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Technology:
Dynamic Underground Stripping-Hydrous Pyrolysis Oxidation (DUS/HPO)
- 3 steam-injection well clusters installed around the perimeter of the 100 ft by 100 ft treatment area; each well cluster consisted of 3 injection wells with screen intervals at 50-70 ft bgs, 110-130 ft bgs , and 150-160 ft bgs
- One dual-phase groundwater and vapor extraction well installed in the center of the target zone with a screen interval from 20-160 ft; this well was operated using a high-temperature electric-submersible pump, located 15 ft below the static groundwater elevation (143 ft bgs)
- 3 vadose zone soil vapor extraction wells along the perimeter of the target zone vapors
- Steam for the system supplied from other industrial operations at the site
- Extracted vapors sent through a heat exchanger, DNAPL-water separator; SVE operated at level that kept contaminant vapor discharge below permitted levels
- Air was injected into the deep saturated zone injection wells to enhance the HPO process
- Initial steam injection to the deep vadose zone was at a maximum design pressure of 60 psig and a temperature of 152ºC; and 40 psig and 143ºC for the intermediate vadose zone
- 14 downhole thermocouple arrays and electrical resistance tomography (ERT) images which displayed changes in subsurface resistance caused by differences in temperature
- Groundwater was heated to a temperature of approximately 100 ºC, while the source zone reached a temperature of approximately 100ºC

Type/Quantity of Media Treated:
Source zone
- Total volume of 52,000 cubic yards based on a surface area of 100 ft by 100 ft and a depth of 160 ft

Dynamic Underground Stripping-Hydrous Pyrolysis Oxidation at the Savannah River Site 321-M Solvent Storage Tank Area, Aiken, Georgia (continued)

Regulatory Requirements/Cleanup Goals:

- The performance objectives for the pilot demonstration were: (1) contaminants must be extracted from the target source zone; (2) the target source zone must be heated to the applied boiling point; and (3) air to support HPO must be injected into the treatment area
- The system must meet discharge limits for vapor emissions and water discharge; however, specific values were not provided

Results:

- From September 2000 through September 2000, a total of 31,000 kg of contaminant were removed (30,000 kg of PCE and 1,000 kg of TCE)
- By March 2001, more than 62% of the TCE mass had been removed compared to 26% of PCE mass; attributed to the lower boiling point of TCE; after March 2001, concentrations and daily removal rates decreased more rapidly for TCE than for PCE, likely due to removing the majority of TCE during initial heating and the relatively higher rate of destruction of TCE by HPO
- Performance objectives were met on March 8, 2001; however system operation was continued until September 26, 2001 for additional contaminant mass removal
- The mass of contaminants destroyed in the subsurface by HPO was not quantified. However, based on estimates from other projects and experimental work at Lawrence Livermore National Laboratory, the vendor indicated that the amount of dissolved phase contaminants expected to be destroyed by HPO would be at least 10% (6,800 lbs) and could be as high as 30% (20,000 lbs) of the contaminant removed by DUS.

Costs:

- The Interstate Technology Regulatory Council (ITRC) reported a project cost of $29/cu yd for the pilot system not including the cost for steam generation and treatment of vapor and dissolved phase contaminants
- No additional information was provided

Description:

The Solvent Storage Tank Area (SSTA) is located west of Building 321M in the M-Area of the U.S. DOE Savannah River Site (SRS), in Aiken, S.C. Building 321M operated as a target fabrication facility, primarily housing metallurgical and mechanical processes such as casting, extrusion, hot-die-sizing and welding. The SSTA included a 17,000 gallon storage tank for chlorinated solvents including PCE and TCE. Numerous spills and leaks were suspected to have occurred in this area. Results of site investigations indicated that DNAPL was present in silts and clays in the vadose zone above the water table at depths ranging from 20 to 35 feet bgs. A pilot-scale demonstration of DUS/HPO was performed from September 9, 2000 to September 28, 2001 to treat DNAPL in the source zone.

A treatment area of 100 ft by 100 ft by 160 ft (52,000 cubic yards) was used for the demonstration. The pilot-scale system included 3 steam-injection well clusters installed around the perimeter of the treatment area; one dual-phase groundwater and vapor extraction well installed in the center of the target zone; 3 vadose zone soil vapor extraction wells along the perimeter of the target zone vapors; and vapor and effluent treatment. Air was injected into the deep saturated zone injection wells to enhance the HPO process. Groundwater was heated to a temperature of approximately 100 ºC, while the source zone reached a temperature of approximately 100ºC. By March 2001, the performance objectives for the pilot-scale demonstration had been met. System operation was continued until September 26, 2001 to remove additional contaminant mass. A total of 31,000 kg of contaminant were removed, including 30,000 kg of PCE and 1,000 kg of TCE. The reported cost for the pilot-scale demonstration was $29/cu yd for the pilot system not including the cost for steam generation and treatment of vapor and dissolved phase contaminants. According to the vendor, the most difficult region of the target zone to heat was the shallow portions at the center of the treatment area. The most likely reason for this was the circulation of air from the surface to the shallow zone. Restricting vapor extraction and continuous long-term steam injection sufficiently heated this portion after five months of steam injection.

In Situ Solidification/Stabilization using the Envirobond™ Process at Two Sites in the Crooksville/Roseville Pottery Area of Concern, Roseville, Ohio

Site Name:
Crooksville/Roseville Pottery Area of Concern (CRPAC)

Location:
Roseville, Ohio

Period of Operation:
September 1998 (long-term monitoring continues)

Cleanup Authority:
RCRA

Purpose/Significance of Application:
To evaluate effectiveness of *in situ* solidification/stabilization for treating lead in soil

Cleanup Type:
Field demonstration

Contaminants:
Lead - 382 mg/L TCLP at inactive pottery facility; 0.05 mg/L TCLP at trailer park

Waste Source:
Improper disposal of lead-containing waste generated from pottery-making processes

Contacts:

EPA Project Manager:
Edwin Barth
LRPCD
Office of Research and Dvelopment
U.S. Environmental Protection Agency
26 W. Martin Luther King Drive
Cincinnati, OH 45268
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(513) 569-7571 (fax)
E-mail: barth.ed@epamail.epa.gov

Technology Developer:
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Rocky Mountain Remediation Services
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Golden, CO 80401
(303) 215-6686 (phone)
(303) 215-6786 (fax)
E-mail: asogue@rmrshq.com

State Lead:
Abby Lavelle
Ohio Environmental Protection Agency
Southeast District Office
2195 Front Street
Logan, OH 43139-9031
(740) 380-5296

Technology:
In situ solidification/stabilization using Envirobond™ process

- Envirobond™ is a combination of proprietary powder and solution developed by Rocky Mountain Remediation Services, L.L.C. (RMRS)
- Consists of a mixture of additives containing oxygen, nitrogen, and phosphorus, with each additive having an affinity for a specific class of metals
- Forms metal complexes that immobilize toxic metals, preventing them from leaching
- Applied at 10 experimental units at a trailer park and one experimental unit at an inactive pottery factory
- Powder applied to surface of experimental unit using a fertilizer drop spreader, and liquid applied over the powder using a watering can; powder and liquid mixed into soil using a garden tiller
- Flyash used to adjust soil pH of each experimental unit to approximately 7.0. Thin layer distributed over surface of experimental unit and tilled into experimental unit.

Type/Quantity of Media Treated:
Soil

- Two areas treated - a trailer park and an inactive pottery facility
- Units at trailer park measured 5 ft X 5 ft, and unit at pottery factory measured 3 ft wide X 6 ft long
- Depth of demonstration in all units was limited to upper 6 inches of soil
- Total volume of soil treated was approximately 5 cy

Regulatory Requirements/Cleanup Goals:

- Reduce concentrations of leachable lead in soil to meet the RCRA/HSWA alternative universal treatment standards (UTS) for lead in contaminated soil; this corresponds to a TCLP lead concentration no higher than one of the following: 1) 7.5 mg/L, or 2) 10 percent of the lead concentration in the TCLP extract from untreated soil.
- Decrease soil lead bioaccessibility by 25 percent or more, as defined by the Simplified In Vitro Test Method for Determining Soil Lead and Arsenic Bioaccessibility

In Situ Solidification/Stabilization using the Envirobond™ Process at Two Sites in the Crooksville/Roseville Pottery Area of Concern, Roseville, Ohio (continued)

Results:

- Mean TCLP lead concentration at the inactive pottery factory was reduced from 382 mg/L to 1.4 mg/L - a reduction of over 99 percent, meeting the alternative UTS for soil
- TCLP lead concentrations in all treated and untreated soil samples from trailer park were either at or slightly higher than the detection limit of 0.05 mg/L, and were not used to evaluate objective
- Soil lead bioaccessibility at the trailer park was reduced by approximately 12.1 percent; soil lead bioaccessibility was not evaluated at the pottery facility.

Costs:

- The total cost for the demonstration was approximately $26,000, broken down into 12 separate categories. The unit cost for the demonstration was $5,176 per cy.
- These costs were used to estimate the cost for a typical application of Envirobond™ at full scale.
- Full scale estimate was a site-specific total cost of $33,220, with a unit cost of $41.16 per cy for treating 807 cy of lead-contaminated soil at a 1-acre site within the CRPAC

Description:

The CRPAC is a former pottery manufacturing area located in eastern Ohio. Lead was used in the glazing step of the pottery finishing process, and improper disposal of the lead-containing waste resulted in contamination of the upper portion of soil in the area. A field demonstration of *in situ* solidification/stabilization using the Envirobond™ process was performed at two sites (a trailer park and an inactive pottery facility) within the CRPAC in September 1998.

The demonstration involved applying Envirobond™ at 10 experimental units at the trailer park and one experimental unit at the inactive pottery facility, treating a total of approximately 5 cy of soil. The two main goals of the demonstration were to evaluate whether Envirobond™ could reduce concentrations of leachable lead in the soil to meet the alternative UTS and whether it could decrease the portion of total lead in soil that is bioaccessible, as measured by the Simplified In Vitro Test Method for Determining Soil Lead and Arsenic Bioaccessibility, by at least 25 percent. Data from the demonstration indicated that the mean TCLP lead concentration at the inactive pottery factory was reduced from 382 mg/L to 1.4 mg/L, which meets the standards. Data from the trailer park were not used to evaluate the goal because TCLP lead concentrations in all treated and untreated soil samples from this location were either at or slightly higher than the detection limit of 0.05 mg/L. Analysis of the data for the second goal showed that soil lead bioaccessibility had been reduced by approximately 12.1 percent, which was less than the project goal of at least 25 percent.

The total cost for the demonstration was $26,000 and the projected total cost for use of this technology to treat 807 cy of soil at full scale was $33,220, with a unit cost of $41.16 per cy.

Lasagna™ at the Paducah Gaseous Diffusion Plant Superfund Site, Solid Waste Management Unit 91, Paducah, Kentucky

Site Name:
Paducah Gaseous Diffusion Plant (PGDP) Superfund Site

Location:
Paducah, Kentucky

Period of Operation:
December 1999 - December 2001

Cleanup Authority:
Federal Facilities Agreement between DOE, EPA, and the Commonwealth of Kentucky. ROD dated July, 1998.

Purpose/Significance of Application:
To reduce TCE concentrations in soil to below cleanup levels using the Lasagna™ technology

Cleanup Type:
Full scale

Contaminants:
TCE

Waste Source:
Improper disposal of chemicals used as part of cylinder integrity testing processes

Contacts:

CDM Federal Programs Corporation
325 Kentucky Avenue
Kevil, KY 42053
(270) 462-3006 (phone)
(270) 462-3060 (fax)

Technology:
Lasagna™

- Uses an applied direct current electric field to drive contaminated soil-water, in a process called electro-osmosis, through treatment zones installed in the contaminated soil
- Soil-water flows from the anode electrode toward the cathode electrode, which is located in the center of the treatment zone
- Treatment zones are vertical zones comprised of iron filings and Kaolin clay (60% by weight iron particles in a 40% by weight Kaolin clay)
- Treatment zone slurry was prepared offsite and transported to Lasagna™ site in a concrete mixer truck; slurry was injected using a hollow mandrel
- Contaminants are broken down into nonhazardous components as they come into contact with the iron particles in the treatment zone
- Elevated soil temperature as a result of current flow through soil also contributes to contaminant mobility and destruction

Type/Quantity of Media Treated:
Soil over a 6,480 ft^2 area in Solid Waste Management Unit (SWMU) 91

Regulatory Requirements/Cleanup Goals:
Risk-based soil TCE cleanup level of 5.6 mg/kg, as specified in ROD

Results:

- Average initial TCE concentration in soil was 84 mg/kg, with a maximum concentration greater than 1,500 mg/kg
- After nine months of operation (August 2000), sampling data showed that average TCE concentration had been reduced to 43.3 mg/kg, with a high of 552 mg/kg
- After 21 months of operation (August 2001), average TCE concentration had been further reduced to less than 1.5 mg/kg, with a high of 27 mg/kg
- Verification sampling in April-May 2002 (after system shutdown) indicated average TCE concentrations of 0.38 mg/kg, with a high of 4.5 mg/kg, less than the cleanup goal of 5.6mg/kg
- GC-MS analysis of select soil samples after system shutdown showed that cis-1,2-dichloroethene and vinyl chloride were either absent or present at very low concentrations

Lasagna™ at the Paducah Gaseous Diffusion Plant Superfund Site, Solid Waste Management Unit 91, Paducah, Kentucky (continued)

Costs:
Total cost for full-scale remediation was approximately $4,000,000, broken down as follows:

- 1999: Remedial design, remedial action work plan, mobilization and construction start: $2,510,000.
- 2000: Construction complete, post construction report, operations and maintenance plan and begin operations and maintenance: $906,000 (this includes $785,000 for construction and $121,000 for operations and maintenance)
- 2001: Continue operations and maintenance, interim sampling report A: $263,000.
- 2002: Interim sampling report B, complete operations and maintenance period, verification sampling and analysis plan, remedial action report: $279,000

There were no regulatory agency oversight costs associated with the project

Description:
SWMU 91 at the PGDP Superfund site in Paducah, Kentucky was used as part of cylinder integrity testing processes from late 1964 until early 1965 and in February 1979. Before the cylinders were tested, they were chilled in a pit containing TCE and dry ice. The TCE was not removed from the pit after the tests, eventually causing contamination of the surrounding soil and groundwater. This report describes activities under one phase of the cleanup, which covered soil contaminated with TCE. Full-scale operation of LasagnaTM began at the site in December 1999 under a Federal Facilities Agreement, and continued for two years until December 2001.

The technology application involved inducing electro-osmosis in the soil using an applied direct current electric field. The soil water was driven to treatment zones consisting of iron filings and Kaolin clay, where TCE was degraded to nonhazardous compounds. The average initial soil concentration of TCE was 84 mg/kg, with a maximum concentration greater than 1,500 mg/kg. The ROD specified a cleanup level of 5.6 mg/kg. After 21 months of operation, average TCE concentrations had been reduced to less than 1.5 mg/kg, with a high of 27 mg/kg. Verification sampling after system shutdown indicated average TCE concentrations of 0.38 mg/kg, with a high of 4.5 mg/kg, thereby meeting the cleanup goal. The total cost for the remediation was approximately $4,000,000, including capital costs, construction, mobilization, and operation and maintenance costs.

During the first two treatment zone installation attempts, the treatment material would not drop out of the mandrel as the mandrel was vibrated out of the ground. It was determined that too many large particles existed in the iron aggregate thereby impeding flow. To address this, the manufacturer re-supplied the treatment material with a smaller grain size to address this. A cost-saving measure implemented during the project was monitoring the system remotely using a data acquisition system, which also had shutdown capabilities for fault conditions.

In Situ Solidification/Stabilization at Koppers Co. (Charleston Plant) Ashley River Superfund Site, South Carolina

Site Name:
Koppers Co. (Charleston Plant) Ashley River Superfund Site

Location:
South Carolina

Period of Operation:
September - December, 2001

Cleanup Authority:
CERCLA
- ROD signed April 1998
- ESD signed August 2001

Purpose/Significance of Application:
Use of solidification/stabilization in river sediments

Cleanup Type:
Full scale

Contaminants:
Polycyclic aromatic hydrocarbons and DNAPL

Waste Source:
Wastewater discharges from wood treating and storage of waste oil

Contacts:

EPA Contact:
Craig Zeller
Remedial Project Manager
Environmental Protection Agency
Region 4
61 Forsyth Street SW
Atlanta, GA 30303
Telephone: (404) 562-8827
Fax: (404) 562-8788
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Technology Vendor:
Mark A. Fleri, P.E.Vice President
Williams Environmental Services, Inc.
2075 West Park Place
Stone Mountain, GA 30087
Telephone: (800) 247-4030/(770) 879-4075
Fax: (770) 879-4831
E-mail: mfleri@wmsgrpintl.com

Technology:
In situ solidification/stabilization (S/S)
- *In situ* S/S using a slurry of cement-based grout augmented with proprietary chemicals
- "Tubular injector" used for injecting and mixing reagents; special amphibious "marsh excavator" used to inject and mix cement-based grout into the upper two feet of sediment
- S/S began at the riverbank and progressed towards the central channel, about 25 feet deep
- Mixing plant was mobilized on site for mixing grout; 181,303 gallons of grout were mixed with the sediment; grout consisted of 632 tons of cement, 3,971 gallons of proprietary chemicals, and 160,000 gallons of water

Type/Quantity of Media Treated:
Sediments
- 2,450 cubic yards of sediment were solidified to a depth of 2 feet

Regulatory Requirements/Cleanup Goals:
- The goal for the S/S treatment was to eliminate contaminant exposure to the benthic community and preclude further potential risks to upper trophic level receptors

Results:
No information was provided about the performance of the solidified sediment and whether/how it met the performance goals

Costs:
- The total cost for this application was $561,154, including the use of a tubular injector and marsh excavator, as well as the grout chemicals, and $242,300 for equipment mobilization and demobilization
- The calculated unit cost was $229 per cubic yard, based on 2,450 cubic yards of sediment

In Situ Solidification/Stabilization at Koppers Co. (Charleston Plant) Ashley River Superfund Site, South Carolina (continued)

Description:
The Koppers Co., Inc. Charleston Plant is located on 102 acres north of downtown Charleston, South Carolina. The site includes part of the Ashley River that is used as a barge canal. Koppers operated the site as a wood-treating facility from 1940 to 1977, primarily treating raw lumber and utility poles with creosote, as well as pentachlorophenol and copper-chromated-arsenate (CCA). The majority of wood-treating operations were conducted in the eastern portion of the site, identified as the Former Treatment Area. Wastewater from these processes was discharged into a ditch. From 1978 to the early 1980s, the site was used for storing wastes, including waste oil. The results of site investigations showed that sediments at the site were contaminated with PAHs and DNAPL, including sediments in the Ashley River.

In situ solidification/stabilization was identified as the remedy for one acre in the active marine area of the river. Bench- and pilot-scale testing were performed to develop a suitable grout and to assess the effectiveness of the remedy at full-scale. Specially-designed equipment was used to solidify an estimated 2,450 cubic yards of sediment in the Ashley River, extending from the riverbank into a channel about 25-ft deep. This included a "tubular injector" used for injecting and mixing reagents, and a special amphibious "marsh excavator" used to inject and mix cement-based grout into the upper two feet of sediment. According to the vendor, this type of equipment allowed grout to be injected at the required depths, and made it possible to use solidified sediment as a platform to reach untreated sediment.

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EX SITU SOIL TREATMENT ABSTRACTS

Thermal Desorption at Site B, Western United States

Site Name:
Site B (actual site name confidential)

Location:
Western United States

Period of Operation:
April to August 1995

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Use of low temperature thermal desorption to treat soil contaminated with a wide range of organochlorine pesticides, including DDT

Cleanup Type:
Full scale

Contaminants:
Pesticides
- p,p'-DDD (DDD), p,p'-DDT (DDT), p,p'-DDE (DDE), hexachlorobenzene, toxaphene, bis(2-ethylhexyl)phthalate, lead, and zinc

Waste Source:
Pesticide formulation operations and management of liquid wastes in lagoons

Contacts:

EPA Contact:
Lynda Priddy
U.S. EPA Region 10
1200 Sixth Avenue
Seattle, WA 98101
Telephone: (206) 553-1987
Fax: (206) 553-0149
E-mail: priddy.lynda@epa.gov

Vendor:
Mark A. Fleri, P.E.
Vice President
Williams Environmental Services, Inc.
2075 West Park Place
Stone Mountain, GA 30087
Telephone: (800) 247-4030/(770) 879-4075
Fax: (770) 879-4831
E-mail: mfleri@wsg1.usa.com

Technology:
Thermal Desportion
- Low temperature thermal desorption (LTTD) system; included six main units - feed system, rotary dryer, baghouse, thermal oxidizer, wet quench, and acid gas scrubber
- Stainless steel, direct-heated rotary kiln dryer approximately 40 ft long and 8.5 ft in diameter; 49 million BTU/hr propane-fired burner, and discharge screw
- Residence Time - 15 to 20 minutes; system throughput - 30 tons of soil/hr; soil exit temperature - 725 ^{o}F to 750 ^{o}F; thermal oxidizer exit gas temperature - > 1,810 ^{o}F
- Contaminated soil screened with a PowerScreen Model Mark IV to remove debris >2 in. long
- Treated soil was moisturized and backfilled on site

Type/Quantity of Media Treated:
Soil/26,000 tons

Regulatory Requirements/Cleanup Goals:
- Cleanup goals were established for 15 organochlorine pesticides as well as arsenic, lead, and mercury in soil
- Goals for pesticides ranged from 0.0588 mg/kg for Aldrin to 400 mg/kg for Methoxychlor. The goal for DDT, one of the most prevalent contaminants at the site, was 2.94 mg/kg
- State's maximum acceptable source impact levels (ASILs) were identified for ground level air and stack emissions

Results:
- Treated soil met the cleanup goals for the 15 organochlorine pesticides and the three metals
- DDT concentrations were reduced to an average of 0.18 mg/kg
- Initially the system did not meet the performance objectives for particulate air emissions, with the average particulate concentration of 0.04 gr/dscf greater than the required 0.03 gr/dscf (corrected to 7% O_2); the system was modified and subsequently met all performance objectives

Thermal Desorption at Site B, Western United States (continued)

Costs:

- The total cost for the LTTD application was $3,260,517, including $429,561 in capital cost and $2,830,956 in O&M costs
- The unit cost was $125 per ton, based on 26,000 tons of soil treated

Description:

Site B (actual site name and location confidential) in the western United States was used for formulation of pesticides from 1938 to 1985. Wastes from the formulation process and an on-site laboratory were discharged to a french drain/sump area and to lagoons. Site characterization activities performed in 1986 showed elevated levels of pesticides in the soil, including p,p'-DDD (DDD), p,p'-DDT (DDT), p,p'-DDE (DDE), hexachlorobenzene, toxaphene, bis(2-ethylhexyl)phthalate, lead, and zinc. As part of a removal action conducted by EPA in1993, soils were excavated and thermal desorption was used to treat contaminated soil.

Thermal treatment system was performed from April to August 1995 using a low temperature thermal desorption (LTTD) system owned by Williams Environmental Services, Inc. The LTTD system included included a feed system, rotary dryer, baghouse, thermal oxidizer, wet quench, and acid gas scrubber. The rotary dryer was a stainless steel direct-heated rotary kiln (40 ft long and 8.5 ft in diameter) fired by a 49 million BTU/hr propane-fired burner. Prior to treatment, contaminated soil was screened to remove oversize material (> 2in.). A total of 26,000 tons of soil was treated with the treated soil meeting the cleanup goals for the 15 pesticides and three metals of concern. Treated soil was moisturized and use as backfill on site. The cost for this application was $3,260,517, including $429,561 in capital cost and $2,830,956 in O&M costs for a unit cost of $125 per ton of soil treated.

Initially the system did not meet the objective set for particulate emissions, attributed to operational problems with the demisters and scrubber. System modifications to address this problem included replacing the fabric mesh demisters in the scrubber with stainless steel chevron demisters, increasing the critical velocity capacity of the demisters, and increasing the blowdown rate from the scrubber to reduce the amount of salts being recycled in the scrubber water. The system met then met its performance objective.

Ex Situ Thermal Desorption using the SepraDyne™-Raduce System at Brookhaven National Laboratory

Site Name:
Brookhaven National Laboratory (BNL)

Location:
Upton, New York

Period of Operation:
Not provided

Cleanup Authority:
Not identified

Purpose/Significance of Application:
To evaluate effectiveness of using the Sepradyne™-Raduce system for removing and recovering mercury from a mixed waste matrix

Cleanup Type:
Field demonstration

Contaminants:
Mercury

Waste Source:
Contaminated soil retrieved from remedial excavation activities of the Animal/Chemical Pits on site and mixed waste from various DOE operations

Contacts:

Technical Project Manager:
Jim Brower
Brookhaven National Laboratory
(631) 433-7513 (phone)
(631) 344-6134 (fax)
E-mail: brower@bnl.gov

DOE-ID Program Director:
William Owca
Transuranic and Mixed Waste Focus Area Manager
U.S. Department of Energy
Idaho Operations Office
850 Energy Drive
Idaho Falls, Idaho 83401-1563
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(208) 526-5964 (fax)
E-mail: owcawa@id.doe.gov

Technology:
Thermal Desorption (*ex situ*)
- High vacuum, indirectly heated rotary retort that removes volatiles from non-volatile matrices
- Air and sweep gases eliminated from retort, minimizing gas exhausted to atmosphere
- Vacuum of at least 25 inches Hg and moderate temperature maintained during operation
- Heat indirectly applied within an insulated firebox fueled by natural gas, diesel oil, or propane
- Following drying phase, temperature raised to a target value, typically in the range of 600-750°C, and held there for a predetermined period

Type/Quantity of Media Treated:
Mixed waste; 3,050 lbs, consisting of soil and waste carcasses

Regulatory Requirements/Cleanup Goals:
- Total mercury concentrations in residuals below 10 ppm
- Universal treatment standards (UTS) of 0.025 mg/L leachable mercury as determined by TCLP tests
- MACT standard of 40 $\mu g/m^3$ for mercury emissions

Results:
System treated mixed waste with a maximum mercury concentrations of 5,510 ppm.
- Final residuals from the process had total mercury levels ranging from 0.55 to 8 ppm
- Leachable mercury levels were 0.008 mg/L or less based on TCLP tests
- Emission of mercury averaged between 1 and 14 $\mu g/m^3$ throughout system operation

Costs:
Based on the demonstration, the projected unit cost to treat waste at full-scale using the Sepradyne™-Raduce system is approximately $0.90 per lb. This estimate is based on a processing rate of 1,000 lb/hr, and assumes operation at full capacity over 10 years. Capital costs are estimated to be $1,500,000. The unit cost includes disposal costs of the associated waste streams (estimated to be $1,000/$m^3$ for solids, $0.10/gal for wastewater, and $25/gal for organics), and excludes decontamination and decommissioning costs.

Ex Situ Thermal Desorption using the SepraDyne™-Raduce System at Brookhaven National Laboratory (continued)

Description:
BNL is a DOE facility located in Upton, New York. The Laboratory conducted remedial excavation activities of the Animal/Chemical Pits on site in 1997, generating mixed waste with elevated concentrations of mercury. A field demonstration using the Sepradyne™-Raduce system was conducted to evaluate the effectiveness of the system in removing and recovering mercury from the mixed waste matrix.

The field demonstration involved treating 3,050 lbs of mixed waste consisting primarily of soil and waste carcasses. The goals of the demonstration were to reduce total mercury concentrations in the treatment residuals to below 10 ppm, reduce leachable mercury concentrations to below 0.025 mg/L TCLP, and reduce air emissions of mercury to below 40 µg/m3. Analysis of the data after the demonstration was complete showed that total mercury levels ranged from 0.55 to 8 ppm, TCLP leachable mercury levels were 0.008 mg/L or less, and air emissions of mercury averaged between 1 and 14 $\mu g/m^3$ throughout operation of the system. These data indicated that the project goals and regulatory requirements were met. The projected unit cost for treating mercury-containing mixed waste using the Sepradyne™-Raduce system is $0.90 per lb, assuming a processing rate of 1,000 lb/hr and full-scale operation over a period of 10 years. This cost includes disposal costs and excludes decontamination and decommissioning costs. Data collected during the demonstration showed that the process was able to provide a final product with a 23% weight reduction. Based on visual inspection, the volume reduction was estimated at approximately 40 to 50%.

Thermal Desorption at Industrial Latex Superfund Site, Wallington, New Jersey

Site Name:
Industrial Latex Superfund Site

Location:
Wallington, New Jersey

Period of Operation:
April 1999 to June 2000

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Use of thermal desorption to treat soil contaminated with a variety of organic contaminants including pesticides, SVOCs, and PAHs

Cleanup Type:
Full scale

Contaminants:
Pesticides, semivolatile organic organic compounds, and PCBs; semivolatile organic organic compounds (SVOCs) such as bis (2-ethylhexyl) phthalate (BEHP), 3,3'-dichlorobenzidene, and polyclic aromatic hydrocarbons (PAHs); and metals such as antimony and arsenic

- Highest concentrations measured were for PCB Aroclor 1260 at 4,000 mg/kg, BEHP at 280 mg/kg, and antimony at 12.6 mg/kg

Waste Source:
Leaking drums

Contacts:

EPA RPM:
Stephanie Vaughn
EPA Region 2
290 Broadway
New York, NY 10007
Telephone: (212) 637-3914
E-mail: vaughn.stephanie@epa.gov

Technology Provider:
Stan Wojinski
Environmental Chemical Corporation
999-18th Street, Suite 2350
Denver, CO 80202
Telephone: (303) 298-7607
E-mail: swojinski@ecc.net

Technology:
Thermal Desorption

- Thermal desorption unit was a "triple dryer", a rotating cylindrical kiln with two concentric cylindrical chambers used to supply indirect heat at 40 million BTU/hr
- Soil was screened to remove material greater than 2 inches in diameter
- System processed an average of approximately 225 tons of soil per day, with a typical soil exit temperature of 900 ºF
- Off gases treated using a scrubber, venturi, and spray tower, followed by a high-efficiency particulate air (HEPA) filter, and a vapor phase carbon filter unit
- Blowdown from off-gas treatment - treated using carbon; water from the scrubber, venturi, and spray tower - treated using a clarifier and filter press
- Treated soil was backfilled on site
- Results of performance test prior to full-scale operation identified elevated levels of particulate emissions at the stack; several system modifications performed to address the issue

Type/Quantity of Media Treated:
Soil

- 53,685 cubic yards

Regulatory Requirements/Cleanup Goals:

- ROD specified cleanup goals as - PCBs - 1 mg/kg; BEHP - 46 mg/kg; 3,3'-Dichlorobenzidene - 1.4 mg/kg; and arsenic - 20 mg/kg
- System operated under an air quality permit that included action levels for ambient air at site boundary locations, and a water discharge permit

Thermal Desorption at Industrial Latex Superfund Site, Wallington, New Jersey (continued)

Results:
- Treated soil was placed into 250 cubic yard bins (260 stockpiles total) and one composite sample was collected from each bin and analyzed for PCBs, SVOCs, and arsenic
- Results showed that concentrations for PCBs, SVOCs, and arsenic in treated soil met the cleanup goals
- 16 of the 260 stockpiles of treated soil (approximately 6%) were retreated because they did not initially meet the cleanup goals

Costs:
- Actual costs for this application - $15,700,000, including capital and O&M costs
- Unit cost of $292 per cubic yard, based on 53,685 cubic yards of soil treated

Description:
The 9.67 acre Industrial Latex Superfund Site, in Wallington, New Jersey was used to manufacture natural and synthetic rubber compounds and chemical adhesives from 1951 to 1983. Solvents used in the manufacturing process included volatile organic compounds (VOCs) such as acetone, heptane, hexane, methyl ethyl ketone, and methylene chloride, as well as PCBs. Leaking drums of various chemical compounds were found at the site and soil and groundwater at the site were determined to be contaminated with PCB Aroclor 1260; semivolatile organic organic compounds (SVOCs) such as bis (2-ethylhexyl) phthalate (BEHP), 3,3'-dichlorobenzidene, and polyclic aromatic hydrocarbons (PAHs); and metals such as antimony and arsenic. The site was added to the Superfund National Priorities List (NPL) in March 1989. The ROD signed in September 1999 specified thermal desorption to address contaminated soil.

From April 1999 to June 2000, thermal desorption was used to treat 53,685 cubic yards of soil. The thermal desorption unit was a "triple dryer" consisting of a rotating cylindrical kiln with two concentric cylindrical chambers. The unit used indirect heat at 40 million BTU/hr. Thermal treatment achieved the cleanup goals for PCBs, BEHP, 3,3'-dichlorobenzidene, and arsenic. Over the course of the cleanup, 16 of the 260 stockpiles of treated soil (approximately 6%) were retreated because they did not initially meet the cleanup goals. During the performance test, elevated levels of particulate emissions were identified and the HEPA filter housing was modified, with particulate emissions reduced to within permitted levels.

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IN SITU GROUNDWATER TREATMENT ABSTRACTS

Mulch Biowall at Altus Air Force Base, Landfill 3, Oklahoma

Site Name:
Altus Air Force Base, Landfill 3 (LF 3)

Location:
Oklahoma

Period of Operation:
July 2002 to ongoing (data available through March 2003)

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Use of a mulch biowall to treat groundwater contaminated with chlorinated solvents

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents
- TCE plume originates from LF-3 and extends southeastward approximately 4,000 feet
- Concentrations of TCE in April 1999 ranged up to 6,110 µg/L

Waste Source:
Disposal of waste in a landfill

Contacts:

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Technology:
Mulch Biowall
- Biowall was 455 ft-long, 24 ft-deep, and 1.5 ft-wide; consisted of approximately 300 cubic yards of shredded mulch (generated by the city), 60 cubic yards of cotton gin compost, and 265 cubic yards of sand
- Biowall was installed using a continuous trenching machine, allowing simultaneous excavation and filling with mulch mixture
- Groundwater flows through the biowall under natural hydrualic gradient to promote contact with the slowly soluble organic matter; microbial processes in the subsurface degrade the mulch, generating breakdown products including metabolic acids, that provide secondary electron donors or fermentable substrates for hydrogen generation, the primary electron donor used in reductive dechlorination
- 10 groundwater monitoring wells and 4 soil vapor monitoring points were installed

Type/Quantity of Media Treated:
Groundwater

Regulatory Requirements/Cleanup Goals:
- The objective for this project was to assess the applicability and feasibility of promoting *in situ* bioremediation of TCE and cDCE in groundwater, and to contain and attenuate a shallow groundwater plume to prevent surface water discharge or off-base migration

Mulch Biowall at Altus Air Force Base, Landfill 3, Oklahoma (continued)

Results:

- After 3 months, the trend of decreasing TCE and increasing cDCE concentrations in groundwater was observed at all monitoring locations located within 30 ft downgradient of the biowall
- Average decrease in TCE concentrations from July 2002 to March 2003 within the biowall was 98.7 percent; the average decrease in downgradient TCE concentrations was 64.5 percent
- As of March 2003, dissolved oxygen levels were depleted in the study area and within the biowall - oxidation-reduction potential had been lowered; sulfate levels were depleted; hydrogen sulfide and methane levels were elevated; and total metabolic acids were elevated, indicating that the conditions in the biowall were highly conducive to reductive dechlorination

Costs:

Capital cost for procuring materials and installing the biowall was $165,000, or approximately $360 per linear foot. Monitoring cost was approximately $17,000 per event, totaling $51,000 for three events. Future cost of O&M is estimated to be $42,000, consisting of biannual monitoring, reporting, and project management.

Description:

LF-3 is located at the eastern portion of Altus AFB. LF-3 received waste materials including garbage, wood, paper, metal, and shop wastes, construction debris, concrete, brush, and several drums of paint waste, which was buried in trenches. Site investigation identified chlorinated solvents in the groundwater, including TCE and cDCE. A TCE plume extending about 4,000 feet downgradient of LF-3 was identified at the site.

A field demonstration of a mulch biowall was conducted at the site to to assess the applicability and feasibility of promoting *in situ* bioremediation of TCE and DCE in groundwater. The mulch biowall was installed using a continuous trenching machine to simultaneously excavate the trench and install the biowall materials. According to the vendor, this approach eliminated the concerns associated with open trenches. Data from the groundwater monitoring wells showed that TCE concentrations were decreasing, reduced by 64.5 to 98.7 percent, and that cDCE concentrations were increasing. Geochemical parameters measured in March 2003 indicated that the conditions in the biowall were highly conducive to reductive dechlorination. Additional monitoring is planned to document the ability of the biowall to sustain biological activity and contaminant mass degradation.

Mulch Biowall at Offutt Air Force Base, Nebraska

Site Name:
Offutt Air Force Base

Location:
Nebraska

Period of Operation:
Completed August 2000

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Use of a mulch biowall to treat groundwater contaminated with chlorinated solvents

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents
- TCE plume extends approximately 3,000 feet
- Concentrations of TCE as high as 2,200 µg/L where the biowall was installed

Waste Source:
Disposal of waste from manufacturing operations

Contacts:

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Technology Provider:
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Technology:
Mulch Biowall
- Biowall was 100 ft-long, 23 ft-deep, and 1 ft-wide; consisted of shredded mulch (generated on-site using shredded trees and leaves) mixed in a 50:50 ratio with coarse sand
- Biowall was installed using a continuous trenching machine, allowing simultaneous excavation and filling with mulch mixture
- Groundwater flows through the biowall under natural hydrualic gradient to promote contact with the slowly-dissolving organic matter; microbial processes in the subsurface degrade the mulch, generating breakdown products including metabolic acids, that provide secondary electron donors or fermentable substrates for hydrogen generation, the primary electron donor used in reductive dechlorination
- 8 groundwater monitoring wells (2 upgradient, 4 downgradient, and 2 control)

Type/Quantity of Media Treated:
Groundwater

Regulatory Requirements/Cleanup Goals:
- No objectives for the field demonstration were identified

Results:
- After 31 months, TCE concentrations 20 ft downgradient of the biowall had been reduced by 70 percent
- The ratio of cDCE, a degradation byproduct, to TCE downgradient of the wall increased over 2 orders of magnitude relative to upgradient conditions after 5 months of treatment; this ratio subsequently dropped as cDCE was converted to vinyl chloride, ethene, and ethane; the control plot showed no decrease in TCE concentrations
- Sampling results showed evidence of that reducing conditions had been established including: depressed oxygen concentrations and oxygen-reduction potentials due to the consumption of organic matter and oxygen by aerobic bacteria; nitrate and sulfate levels also declined, while methane production was observed

Mulch Biowall at Offutt Air Force Base, Nebraska (continued)

Costs:
- Costs for installing the biowall was $360/linear ft
- If mulch for applications had not been generated on-site (at no cost), the estimated cost was approximately $20/yd^3

Description:
Offutt Air Force Base in Nebraska was used for the manufacture of aircraft. Wastes from operations resulted in groundwater at the site becoming contaminated with chlorinated solvents. TCE concentrations in groundwater were found as high as 2,200 µg/L where the biowall was installed, with a TCE plume identified at the site extending 3,000 ft.

A field demonstration of a mulch biowall was conducted at the site. The mulch biowall was installed using a continuous trenching machine to simultaneously excavate the trench and install the biowall materials. Data from the groundwater monitoring wells showed that, after 31 months, TCE concentrations had been reduced by 70 percent, and that reducing conditions had been established. Demonstration findings suggested that mulch biowalls are appropriate at sites with shallow (less than 8 ft) ground water and where the wall extends less than 30 ft below ground surface. Performance data from the demonstration test indicated that the biowall is a low-maintenance, cost-effective, in-situ treatment wall technology. Based on these results, a full-scale 500-ft biowall was installed at Offutt AFB in July 2001.

Enhanced *In situ* Biotransformation at the Naval Weapons Industrial Reserve Plant, Dallas, Texas

Site Name:
Naval Weapons Industrial Reserve Plant (NWIRP)

Location:
Dallas, Texas

Period of Operation:
October 1999 - September 2000

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Evaluation of the effectiveness and feasibility of *in-situ* biotransformation using molasses to treat groundwater contaminated with chlorinated solvents

Cleanup Type:
Field demonstration

Contaminants:
VOCs
- TCE (26.5-5,300 µg/L) and daughter products, including 1,1-DCE, 1,2-DCE isomers, and vinyl chloride

Waste Source:
Unlined pits that received liquid wastes generated from the manufacture and assembly of military and commercial aircraft components and weapons systems

Contacts:

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Technology:
Enhanced *in situ* biotransformation
- Injection of diluted raw blackstrap molasses into impacted groundwater bearing zones
- 2 injection wells, one in the upper (12 ft bgs) and one in the lower water-bearing zone (approximately 35 ft bgs)
- Injection and monitoring wells installed near center of TCE plume
- Total of approximately 560 gallons of molasses injected into upper zone and 140 gallons into lower zone, over a period of two months
- 13-52 gal. injected in upper zone and 0-35 gal. injected in lower zone per event
- Concentration of molasses ranged from 10-20 %
- Injection events occurred every 2-3 days
- Larger volumes of molasses (325-1,800 gal. at 2% concentration) injected in latter stages of demonstration to evaluate hydrodynamic effects of creating small groundwater mounds around injection wells

Type/Quantity of Media Treated:
Groundwater
- Two water-bearing zones in study area (unlined acid neutralization pit near Solid Waste Management Unit #15 that received liquid wastes from site operations between 1970 and 1983)
- Depth of upper zone is 12 ft bgs and depth of lower zone is approximately 35 ft bgs
- Laterally and vertically anisotropic and heterogeneous hydrogeology
- Hydraulic conductivity: upper water-bearing zone - 35.7 to 13.5 ft/day; lower water-bearing zone - 29.0 to 2.2 ft/day; upper and lower water-bearing zone (not separated) - 6.2 to 1.4 ft/day

Regulatory Requirements/Cleanup Goals:
Objective of study was to evaluate enhanced *in situ* biotransformation as a remedy for impacted groundwater. No cleanup goals were established.

Enhanced *In situ* Biotransformation at the Naval Weapons Industrial Reserve Plant, Dallas, Texas (continued)

Results:
Data were provided for six downgradient monitoring wells (three in the upper and three in the lower water-bearing zone) for baseline samples that were collected in July 1999 prior to installing the treatment system, and again in September 2000. During this period, TCE concentrations appeared to have been reduced more in the upper water-bearing zone than in the lower water-bearing zone

- In the upper zone, TCE concentrations were reduced from 4,110 to 323 µg/L and from 3,310 to 345 µg/L in two out of the three downgradient monitoring wells. In the third monitoring well, TCE concentrations stayed approximately the same at 378 µg/L
- In the lower zone, TCE concentrations were reduced from 2,770 to 2,300 µg/L in one out of the three downgradient monitoring wells. In the other two wells, TCE concentrations increased from 1,020 to 2,150 µg/L and from 3,170 to 4,450 µg/L

Costs:

- The total cost for the pilot study was $306,557, including $152,903 in capital costs, $72,560 in O&M costs, and $27,094 in other project costs such as reporting and project management
- Unit cost was not calculated for this application
- No information was provided about the projected cost for use of this technology at full-scale at this site

Description:
The NWIRP in Dallas, TX is an active plant that manufactures and assembles military and commercial aircraft components and weapons systems. Improper disposal of degreasers in these operations resulted in contamination of the groundwater with TCE and its daughter products. In October 1999, a field demonstration of enhanced *in situ* biotransformation was initiated in an area near Solid Waste Management Unit (SWMU) #15, which was an unlined acid neutralization pit that received liquid wastes from site operations between 1970 and 1983.

The demonstration consisted of injecting molasses solution into the upper and lower water-bearing zones using two injection wells, to serve as a supplemental energy source for indigenous microbes and enhance the existing microbial processes occurring within the subsurface. After an 11 month period, sampling showed that TCE concentrations appeared to have been reduced more in the upper water-bearing zone than in the lower water-bearing zone. In the upper zone, TCE concentrations were reduced by more than 85% in two out of the three downgradient monitoring wells, while they stayed approximately the same in the third well. In the lower zone, TCE concentrations were reduced by approximately 15% in one out of the three downgradient wells, and increased in the other two wells. No information was provided about the projected cost for use of this technology at full-scale at this site. During the demonstration, mold was found to be growing on the molasses solution. As a result, the solution was prepared in batches and automated injection was switched to manual events followed by thorough cleaning of the molasses mixing tanks.

In Situ Bioremediation Using Hydrogen Release Compound® Or Other Amendments At Four Drycleaner Sites, Various Locations

Site Name:
Multiple (4) Dry Cleaner Sites - *In Situ* Bioremediation

Location:
- Asian Cleaners, Sanford, FL
- Cypress Village Shopping Center, Bridgeton, MO
- Dry Clean USA #11204, Fort Lauderdale, FL
- Tiger Cleaners, Memphis, TN

Period of Operation:
- Asian Cleaners - January 11, 2002 - date unspecified
- Cypress Village Shopping Center - technology not yet approved
- Dry Clean USA - December, 2002 - January, 2003 (demonstration only)
- Tiger Cleaners - Expected to begin remediation in April, 2002

Cleanup Authority:
State

Purpose/Significance of Application:
Use of *in situ* bioremediation to treat chlorinated solvents in groundwater at drycleaner facilities

Cleanup Type:
Full scale remediations and field demonstrations

Contaminants:
Chlorinated Solvents
- All of the sites were contaminated with PCE, TCE, cis- and trans-1,2-DCE, and vinyl chloride.
- Concentrations varied by site ranging from 5.2 to 87,200 µg/L for PCE, 4.5 to 28,500 µg/L for TCE, 546 to 23,200 µg/L for cis-1,2-DCE, 1,780 to 26,300 µg/L for trans-1,2-DCE, and 1,100 to 2,800 µg/L for vinyl chloride.
- One site (Asian Cleaners) also reported the presence of nonhalogenated volatiles including toluene, p-isopropyltoluene, xylenes, and MTBE.

Waste Source:
Waste and wastewater from drycleaning operations

Contacts:
Varied by site

Technology:
In Situ Bioremediation
- At Asian Cleaners, enhanced bioremediation using triethylphosphate and nitrous oxide was implemented. The system consisted of four biosparging wells screened at 33 to 35 ft bgs - one slant well (installed beneath the drycleaning facility) and three vertical wells. The radius of influence was 31 to 33 ft, and the injection rate was 1 scfm per well, sparging from two wells at a time in one-hour intervals twice per day. Injection concentrations by volume in air were 0.07% to 0.1% for nitrous oxide and 0.007% for triethylphosphate. Propane was scheduled to be added at the end of the treatment regimen to improve microbial concentrations. SVE was used to remove vadose zone contaminants at this site.
- At Cypress Village Shopping Center, use of Hydrogen Release Compound® (HRC®) in the bioremediation process has been evaluated but has not yet been approved.
- At Dry Clean USA, bioremediation using CL Solutions' Cl-Out was used in a demonstration. The solution was introduced into the subsurface in two events. Three injection wells screened between 5 to 10 bgs were used, and approximately 20 gallons of solution were injected in each well per event, at a rate of 1 gallon - At Tiger Cleaners, HRC® will be injected within and outside the source area, as well as in the contaminant plume. Within the source area, seven horizontal injection points will be drilled under the slab of the building, injecting a total amount of approximately 4,000 lbs of HRC®. per minute.

Type/Quantity of Media Treated:
Groundwater
- Groundwater conditions varied by site
- Plume sizes ranged from 4,375 to 20,000 square feet

In Situ Bioremediation Using Hydrogen Release Compound® Or Other Amendments At Four Drycleaner Sites, Various Locations (continued)

Regulatory Requirements/Cleanup Goals:
- At all four sites, cleanup goals were based on state regulatory goals or EPA MCLs.
- Specified cleanup goals for groundwater included 3 µg/L for PCE, 3 µg/L for TCE, 70 µg/L for cis-1,2-DCE, 100 µg/L for trans-1,2-DCE, and 1 µg/L for vinyl chloride.

Results:
- No information was provided for Asian Cleaners, Cypress Village Shopping Center, or Tiger Cleaners.
- At Dry Clean USA, sampling of the source area one month after the second and final injection revealed a decrease in PCE and TCE concentrations from 48,300 to 96 µg/L and from 6,110 to 100 µg/L, respectively. Concentrations of cis-1,2-DCE and vinyl chloride increased from 2,950 to 94,500 µg/L and from 890 to 2,810 µg/L, respectively.

Costs:
- Reported design and implementation cost ranged from approximately $51,000 to $150,000
- O&M costs were provided for one site (Asian Cleaners) - $150,000 estimated for 12 months.

Description:
In situ bioremediation was conducted at four drycleaner sites contaminated with chlorinated solvents from drycleaning operations with TCE and PCE as the primary contaminants in groundwater. The concentrations of TCE and PCE contamination varied by site with levels of PCE in groundwater as high as 87,200 µg/L and TCE in groundwater as high as 28,500 µg/L. The remediations, including full-scale and demonstration-scale projects, involved the subsurface injection of substances to promote bioremediation.

In situ bioremediation was performed using triethylphosphate/nitrous oxide at one site and CL Solutions' Cl-Out at another site. HRC® was evaluated for use at the third site, but has not been approved yet. At the fourth site, bioremediation using HRC® was expected to begin in April, 2002. Results from a sampling event in the source area one month after injection of the Cl-Out solution at Dry Clean USA showed a decrease in PCE and TCE concentrations, and an increase in cis-1,2-DCE and vinyl chloride concentrations.

Electrical Resistive Heating at Poleline Road Disposal Area (PRDA), Arrays 4, 5, and 6, Fort Richardson, Alaska

Site Name:
Fort Richardson

Location:
Fort Richardson, Alaska

Period of Operation:
July through October 1999

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Use of ERH to treat chlorinated solvents in a source zone

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated solvents
- Maximum concentrations in soil - PCE - 120 mg/kg; TCE - 640 mg/kg; PCA - 12,000 mg/kg
- Maximum concentrations in groundwater - PCE - 0.30 mg/L; TCE - 7.8 mg/L; PCA - 18 mg/L
- DNAPL was observed in groundwater

Waste Source:
Disposal of waste from various operations

Contacts:

Regulatory Contacts:
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Technology System Vendor:
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Current Environmental Solutions
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Telephone: (509) 371-0905
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Technology:
Electrical Resistive Heating (ERH)

Type/Quantity of Media Treated:
Source zone (saturated and unsaturated)
- Estimated to be 13,000 tons or 7,333 yds^3 based on a treatment area of approximately 110 ft long by 50 ft wide by 36 ft deep

Regulatory Requirements/Cleanup Goals:
- The objective of this field demonstration was to evaluate the effectiveness of ERH in reducing the concentration of chlorinated solvents in groundwater. Performance of the system was evaluated by monitoring the ability of the system to: heat the soil in the study area; increase the removal rate of contaminants, as compared to previous ERH tests conducted at the site; effectively remove VOCs from the soil and groundwater
- Goals for the site, established in the ROD, were - PCE - 0.005 mg/kg groundwater and 4 mg/kg soil; TCE - 0.005 mg/kg groundwater and 0.015 mg/kg soil; and PCA - 0.052 mg/kg groundwater and 0.1 mg/kg soil

Electrical Resistive Heating at Poleline Road Disposal Area (PRDA), Arrays 4, 5, and 6, Fort Richardson, Alaska (continued)

Results:
- Estimated mass of TCE, PCE, and PCA removed in the off-gas was 1,385 lbs
- The ERH system reduced groundwater concentrations of PCA, PCE and TCE an average of 49 percent, 75 percent and 56 percent; however, at the end of the field demonstration, concentrations of PCA, PCE, TCE, and cis-1,2-DCE were above the remedial action objectives
- The ERH system reduced soil concentrations of PCA and PCE to below the remedial action objectives; however, TCE concentrations remained above the remedial action objective

Costs:
- Cost information was not provided for this application.

Description:
Fort Richardson, established in 1940 as a military staging and supply center during World War II, is located approximately 10 miles northeast of Anchorage, Alaska and occupies about 56,000 acres. Its current mission is to provide services, facilities, and infrastructure to support the rapid deployment of Army forces. The site was added to the National Priority List (NPL) in June 1994 and the site cleanup is being addressed under a Federal Facilities Agreement (FFA) to address contamination at the site. The Poleline Road Waste Disposal Area (PRDA) was used as a disposal area from 1950 to 1972. Results of a site investigation that soil and groundwater has been contaminated with chlorinated solvents including TCE, PCE, and TCA.

ERH was evaluated as a potential remediation technology for the site. This report describes the field demonstration of ERH performed from July through October 1999, conducted in Area A-3 of the PRDA, using heating arrays labeled 4, 5, and 6. The field demonstration covered a treatment area of approximately 110 feet long by 50 feet wide by 35 feet deep. The ERH system was constructed in three phases, with each phase including an electrode array (seven electrodes installed to a depth of 38 feet), three SVE wells, and two thermocouples installed in each phase. The ERH system reduced contaminant concentrations in groundwater by as much as 75 percent. However, at the end of the demonstration, PCA, PCE, TCE, and cis-1,2-DCE were above the remedial action objectives. PCE and PCA concentrations in soil were reduced to below the remedial action objectives; however, TCE concentrations remained above the goal.

Steam Enhanced Extraction (SEE) at the A.G. Communications Systems Site, Northlake, Illinois

Site Name:
A.G. Communications Systems

Location:
Northlake, IL

Period of Operation:
September 1995 to November 1999

Cleanup Authority:
State voluntary cleanup

Purpose/Significance of Application:
Use of SEE in conjunction with SVE to treat a source zone (saturated and unsaturated) contaminated with chlorinated solvents

Cleanup Type:
Full scale

Contaminants:
Chlorinated solvents (TCE, cis-1,2-DCE), petroleum hydrocarbons (xylene and benzene)
- TCE concentration of greater than 45,000 ug/L in groundwater

Waste Source:
Spills and leaks from the manufacture of telecommunications equipment

Contacts:

Site Contact:
Brian LeMaster
Environmental and Safety Specialist
A.G. Communication Systems
Northlake, IL 60164

Technical Contact/Vendor:
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Technology:
Steam Enhanced Extraction (SEE)
- System included shallow vapor extraction wells, shallow and deep steam injection wells, vacuum-enhanced groundwater/vapor extraction wells, deep groundwater extraction wells, and two vacuum extraction units
- 65 steam injection wells, including 39 shallow wells screened a depth of 35 ft bgs and 26 deep wells screened at a depth of 46 ft bgs
- Steam supplied by a 294 kilowatt boiler at pressures ranging from 3 to 7 psi; during operation, soil temperatures ranged from 84°F to 140°F, and groundwater temperatures ranged from 68°F to 165°F
- SVE system - 186 shallow wells and 76 combination groundwater/vapor extraction wells; two vapor extraction units operated at 150 to 250 scfm at 7 to 15 inches of mercury
- Groundwater extracted from the combination groundwater/vapor extraction wells at a rate ranging from 15 to 30 gpm; treated using air stripping and activated carbon

Type/Quantity of Media Treated:
Source zone (saturated and unsaturated)
- Estimated 330,000 cubic yards treated

Regulatory Requirements/Cleanup Goals:
- The remedial objective was to obtain IEPA approved closure under Tiered Approach to Corrective Action guidelines
- The proposed closure strategy was to use site-specific parameters to calculate a first order degradation constant and demonstrate that there are no on-site or off-site receptors at risk from volatile organic hydrocarbons in soil or groundwater

Steam Enhanced Extraction (SEE) at the A.G. Communications Systems Site, Northlake, Illinois (continued)

Results:

- Average TCE groundwater concentrations reduced from approximately 20,000 ug/L to <1,000 ug/L over the period from September 1995 to September 1997
- Data from individual wells showed reductions of >90% for TCE and DCE from December 1995 to October 1997
- Through November 1999, more than 33,000 lbs of hydrocarbons had been removed from soil vapor and groundwater; approximately two-thirds of the contaminant mass was removed as vapor from the two VES units
- According to the vendor, based on the site-specific first order degradation constant, the calculated groundwater concentrations at the point of compliance (property boundary) met Class I remediation objectives; where the soil concentrations beneath the building exceeded the soil remediation objectives, a theoretical groundwater concentration leached from the soil was calculated and, along with the site specific degradation constant, was shown to meet the Class I remediation objectives at the point of compliance

Costs:

- Actual cost for the application was $4.9 million and $13 to 15 per cubic yard treated, including the cost of the pilot test, system design and installation, five years of operation and maintenance, and negotiations with IEPA.

Description:

The A.G. Communications site, located near Chicago, IL, operated as a telecommunications manufacturing facility from the 1950s through the early 1990s. TCE and mineral spirits used in manufacturing operations were stored in underground storage tanks (UST). During the decommissioning of the manufacturing facility, TCE, DCE and components of mineral spirits, including xylene and benzene, were found in soil and groundwater in the vicinity of the former tank farm area and beneath the manufacturing plant. The site was remediated under the Illinois Environmental Protection Agency (IEPA) voluntary site remediation program (SRP). A SEE system was pilot tested at the site from January through July 1994, and full-scale remediation was performed from September 1995 to November 1999.

The full-scale system included shallow vapor extraction wells, shallow and deep steam injection wells, vacuum-enhanced groundwater/vapor extraction wells, deep groundwater extraction wells, and two vacuum extraction units. Through November 1999, a total of 33,000 pounds of hydrocarbons had been removed from soil vapor and groundwater, with TCE and DCE concentrations reduced by more than 90%. In addition to SEE, chemical oxidant flushing using chlorine dioxide ($Cl0_2$) was performed in recalcitrant source areas. According to the vendor, this approach was used to enhance TCE partitioning from soil for removal through the groundwater/vapor extraction wells, and redox levels of -100 to -200 mV were achieved. No additional information about the flushing was provided.

Electrical Resistive Heating at the ICN Pharmaceuticals Incorporated Site, Portland, Oregon

Site Name:
ICN Pharmaceuticals Inc

Location:
Portland, Oregon

Period of Operation:
May 2000 to December 2001

Cleanup Authority:
CERCLA
- ROD signed August 23, 1999
- ESD signed April 4, 2000

Purpose/Significance of Application:
Use of ERH, in conjunction with SVE, to treat DNAPL in a source zone

Cleanup Type:
Full scale

Contaminants:
Chlorinated solvents
- TCE, cis-1,2-DCE, and VC
- DNAPL suspected based on presence of contaminants in groundwater at >1% of solubility

Waste Source:
Dry well used for the disposal of laboratory wastes

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Technology:
Electrical resistive heating (ERH) - Six-Phase Heating™
- Initial ERH system (May 2000 to May 2001) - 60 electrodes - each capable of directing power to three zones 20-30 ft bgs, 34-44 ft bgs, and 48-58 ft bgs; electrodes placed in hexagonal arrays of 6 electrodes each, with a seventh neutral electrode in the middle of each array; annular borehole spaces packed with steel shot to improve conductivity and covered with an impermeable material; 13 subsurface pressure monitoring points and 8 subsurface thermocouples
- 95 kW transformer was used to convert standard three-phase electrical power to six separate phases; initial heating was limited to the bottom interval (45 to 58 feet bgs) to establish a "hot floor" and prevent downward migration of contamination
- During operation, steam and hot water were observed outside the treatment area; 50 "electrode vents" and the treatment system was expanded in May 2001 to treat areas where contaminated steam and hot water had been observed
- Expanded system - added 13 electrodes, 17 electrode vents, and one thermocouple
- An SVE system, consisting of 53 vapor extraction wells, was used to recover the steam and contaminant vapors from the unsaturated region immediately above the heated region (5-10 ft bgs)

Type/Quantity of Media Treated:
Source zone (saturated and unsaturated)
- Estimated 48,000 to 65,000 cubic yards based on a treatment area of three-quarters to one acre in size and a depth of 40 ft
- Groundwater - plume size estimated to be 120 ft by 80 ft

Electrical Resistive Heating at the ICN Pharmaceuticals Incorporated Site, Portland, Oregon (continued)

Regulatory Requirements/Cleanup Goals:

- The remedial action objectives specified in the ROD were to prevent and contain migration of separate-phase DNAPL during treatment and reduce contaminant groundwater concentrations to levels that indicate DNAPL has been removed or treated
- The ROD indicated that the primary goal of the action was to remediate DNAPL and that the residual risk to human health and the environment and the need for further remediation would be assessed following remediation of the DNAPL.

Results:

- TCE, DCE, and VC concentrations were monitored in the Overbank layer and DCE, VC, and benzene concentrations were monitored in the TGA layer of the site
- As of December 2001, maximum groundwater contaminant concentrations in the Overbank layer had been reduced from 150,000 µg/L to 100 µg/L for TCE, from 370,000 µg/L to 1,300 µg/L for DCE, and from 24,000 µg/L to 50 µg/L for VC
- Through June 2002, TCE concentrations decreased to 8.11 µg/L while DCE and VC concentrations were unchanged in the Overbank layer; the concentrations of all three contaminants were above Oregon MCLs
- As of December 2001, the concentrations of DCE and benzene had increased to 49.5 µg/L and 200 µg/L, respectively. VC concentrations decreased from 2.11 µg/L to not detected
- According to the vendor, the increase in benzene concentrations indicated a possible compromise in 3 well casings which provided a conduit for contamination migration from the Overbank layer and these wells were abandoned in April 2002

Costs:

No cost data were provided for this application

Description:

The ICN Pharmaceuticals site, located in Portland, Oregon, was used as a clinical laboratory from 1961 to 1980. A variety of organic and inorganic compounds were used, with wastes from laboratory operations disposed in a 20 ft deep dry well. Results of sampling conducted in the vicinity of the former dry well showed elevated concentrations of volatile organic compounds (VOCs) including trichloroethene (TCE), cis-1,2-dichloroethene (DCE), vinyl chloride (VC), benzene, and toluene in the groundwater, and was determined to be the source of the contamination. During additional investigations, TCE, DCE, and VC were detected in the groundwater at concentrations greater than 1% of their solubility, suggesting the presence of dense non-aqueous phase liquid (DNAPL). The ROD for the site specified ERH (Six-Phase Heating™) as the selected remedy to treat DNAPL. ERH, in conjunction with SVE, was conducted at the site from May 2000 to December 2001.

The remedial action objectives for the site were to prevent and contain migration of separate-phase DNAPL during treatment and to reduce contaminant groundwater concentrations to levels that indicate DNAPL has been removed or treated. As of December 2001, maximum groundwater contaminant concentrations in the Overbank layer had been reduced to 100 µg/L for TCE, 1,300 µg/L for DCE, and 50 µg/L for VC with concentrations above Oregon MCLs as of June 2002. In the TGA layer, concentrations of VC were reduced, but concentrations of DCE and benzene in the TGA layer increased as a result of a possible compromise in the well casings; these wells were abandoned in April 2002. Because dissolved phase VOCs remained above DEQ generic risk-based screening levels at various locations at the site, biosparging was planned for September 2002, as part of the IRAM. Groundwater monitoring at the site is continuing. Information was not provided about whether the biosparging was implemented and any potential results of the biosparging.

Electrical Resistive Heating Treatment of DNAPL Source Zone at Launch Complex 34, Cape Canaveral Air Force Station, Florida

Site Name:
Cape Canaveral Air Force Station, Launch Complex 34

Location:
Cape Canaveral, Florida

Period of Operation:
August 18, 1999 to July 12, 2000

Cleanup Authority:
Not Provided

Purpose/Significance of Application:
Field demonstration of resistive heating using a novel electrode design to treat a DNAPL source area

Cleanup Type:
Field Demonstration

Contaminants:
Halogenated VOCs
- TCE - Estimated mass of 11,313 kg in test plot
- DNAPL - 10,490 kg of the TCE mass was estimated to be DNAPL

Waste Source:
Wastes from rocket engine and parts cleaning operations

Contacts:

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Project Manager
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

William Heath
Current Environmental Solutions

Technology:
In Situ Thermal Treatment (Electrical Resistive Heating)
- Field demonstration of resistive heating - source zone test plot was 75 ft by 50 ft by 45 ft deep
- 13 electrodes, each consisted of two conductive intervals (25-30 ft bgs and 38-45 ft bgs); lower heating interval configured to provide a "hot floor" for the treated aquifer; total of 1.7 million kW-hrs of energy applied to the subsurface (10 to 400 amps)
- Novel design for the electrodes used for the demonstration - an electrical cable attached to a ground rod within a graphite backfill rather than the traditional pipe electode
- 12 SVE wells installed with 2-ft screens to depth of 4-6 ft bgs; off-gases treated with GAC
- Two major system interruptions during the demonstration - hurricane in September 1999 and replacement of a transformer in March 2000
- Excessive rainfall from the hurricane caused the water table to rise, resulting in insufficient heating of the shallow portion of the test plot; to address the problem, ground rods were installed near the electrodes to heat the 5-10 ft bgs interval

Type/Quantity of Media Treated:
Soil and Groundwater
- Test plot size - 75 ft by 50 ft by 45 ft

Regulatory Requirements/Cleanup Goals:
- The objective of the field demonstration was to reduce the contaminant mass by 90 percent

Results:
- The mass of TCE and DNAPL in the soil in the test plot was reduced by 90 percent and 97 percent, respectively, exceeding the target of 90 percent mass removal
- Heating was found to be more efficient in the deeper portion of the aquifer, with less heating observed in the shallow portion
- Limitations in the new electrode design and the loss of the vadose zone during the high rainfall event may have contributed to lower heating of the shallow zone
- Sampling hot cores of soil (90°C) may have resulted in some losses of chlorinated VOCs during post- demonstration

Electrical Resistive Heating Treatment of DNAPL Source Zone at Launch Complex 34, Cape Canaveral Air Force Station, Florida (continued)

Costs:

- The total cost for the project was $613,000, including $569,000 for resistive heating by the vendor and $44,000 in waste disposal costs paid by NASA
- The $569,000 costs for the resistive heating demonstration included costs for design, equipment, mobilization/demobilization, and operation

Description:

A 1998 site investigation at the Cape Canaveral Air Force Station in Florida identified a large DNAPL source at Launch Complex 34. Historical activities at the site included discharging wastes generated from rocket engine and parts cleaning operations into discharge pits. Chlorinated solvents, including TCE, were used in these cleaning operations. The Interagency DNAPL Consortium selected this site for demonstrating DNAPL treatment technologies. One of the technologies tested was resistive heating.

A field demonstration of resistive heating was performed from August 18, 1999 to July 12, 2000, with the post-demonstration assessment performed from August to December 2000. The resistive heating system included 13 electrodes with a novel design - an electrical cable attached to a ground rod within a graphite backfill rather than the traditional pipe electode. During system operation, excessive rainfall resulting from a hurricane raised the water table, resulting in the loss of the vadose zone, and insufficient heating of the shallow portion of the aquifer. Ground rods were installed near the electrodes to heat the 5-10 ft bgs interval. Resistive heating reduced the contaminant mass in the test plot by 90 percent for TCE and 97 percent for DNAPL, exceeding the target of 90 percent mass removal. The vendor used a numebr of techniques, including capping the ends of the core sample, to reduce the potential for loss of VOCs during sampling of hot cores.

Multi-Site *In Situ* Air Sparging, Multiple Locations

Site Name:
Multiple (10) Sites - Air Sparging

Location:
Various

Period of Operation:
Varied by site

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Multi-site study of *in situ* air sparging to evaluate the Air Sparging Design Paradigm

Cleanup Type:
Field demonstration and full scale

Contaminants:
Volatile and Semi-volatile organics and PAHs
- Variety of contaminants at the sites including BTEX, anthracene, napthalene, MTBE, TCE, DCE, VC, benzene, TPH, and PCE

Waste Source:
Varied by site, including waste disposal in landfills, leaks from fuel and POL storage, and firefighter training areas

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Technology:
Air Sparging
- Total of 10 projects - systems included 6 sites with *in situ* air sparging and 4 sites with *in situ* air sparging/SVE; both full-scale and demonstration-scale projects
- Sampling and monitoring procedures varied depending on site conditions and system configuration; included soil gas testing, vapor sampling, groundwater sampling, air flow and air injection pressure monitoring, and helium tracers

Type/Quantity of Media Treated:
Soil and Groundwater
- Quantity treated varied by site

Regulatory Requirements/Cleanup Goals:
- The objective of the study included determining whether the Air Sparging Design Paradigm was effective and valid based on data collected during the study

Results:
- The data supported the necessity to use a suite of diagnostic tests in designing and installing air sparging systems rather than relying on one type of testing; such diagnostic tests included pressure response testing, deep vadose zone helium tracer testing, and dissolved oxygen monitoring
- The data indicated that the 15-ft well spacing prescribed in the design paradigm would have been sufficient to achieve adequate treatment of the target zone
- Many of the air sparging systems in the study were poorly instrumented and monitored to the extent that system performance was compromised

Costs:
- Costs for the demonstration air sparging system at Port Hueneme, CA was $189,880 or $130 per cubic yard, based on 1,500 cubic yards of soil treated
- Projected full-scale costs for this system were $268,490 or $179 per cubic yard based on 1,500 cubic yards of soil treated

Multi-Site *In Situ* Air Sparging, Multiple Locations (continued)

Description:
In the mid-1990s, the U.S. Air Force Research Laboratory, Airbase and Environmental Technology Division, Tyndall AFB, initiated an air sparging project, funded by AFRL/MLQE, SERDP, and U.S. NFSEC. A key goal of the project has been the development of a technically defensible and praticable Air Sparging Design Paradigm. This paradigm was evaluated based on information at 10 sites to determine whether it was effective at evaluating air distribution and to use the results to modify the paradigm.

The 10 sites selected for the study included sites with air sparging systems in place that were being used to treat various soil types and various contaminants. The results of the study showed that many aspects of the Air Sparging Design Paradigm were effective, with the results of the study used to develop the final Air Sparging Design Paradigm.

Cometabolic Air Sparging at McClellan Air Force Base, OU A, Sacramento, CA

Site Name:
McClellan Air Force Base (AFB), OU A

Location:
Sacramento, CA

Period of Operation:
Air sparging initiated May 12, 1999; operted 540 days

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Field demonstration to compare cometabolic and non-co-metabolic air sparging to treat CAHs in groundwater

Cleanup Type:
Field demonstration

Contaminants:
Halogenated Volatiles
- Target chlorinated aromatic hydrocarbons (CAHs) for the demonstration included TCE, DCE, vinyl chloride, TCA, and lower ethene isomers
- TCE concentrations as high as 500 mg/L in the test area

Waste Source:
Former demolition and scrap material burning and burial pit

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Technology:
Cometabolic Air Sparging
- Demonstration system included sparge wells, SVE wells, multi-level groundwater and soil monitoring points, an air injection system, and SVE blower, propane gas storage and injection system, and an on-site field trailer; performed in two phases - Phase 1 focused on groundwater; Phase 2 on unsaturated zone
- Two test plots used for the demonstration - one to test cometabolic air sparging (injection of air and a gaseous organic growth substrate to promote *in situ* cometabolic degradation) and the other to serve as a control; the cometabolic test plot received propane and air and was identified as the "active zone"; the "control zone" test plot received air only; the air sparge wells were located 100 ft apart
- Each plot was equipped with an air injection well, air compressor (25 psi and 15 scfm), and six multi-level groundwater and soil gas monitoring points used to monitor the saturated and vadose zones
- Special safety considerations employed to reduce the risk of explosives hazard from propane
- SVE system - one vapor extraction well was installed next to each sparge well, each well was screened to a depth of 90 ft bgs; designed to extract 45 scfm per well; extracted vapor treated using GAC prior to discharge
- After 500 days of operation, propane degradation was not observed in the saturated zone; methane was substituted for propane to stimulate cometabolic degradation

Type/Quantity of Media Treated:
Groundwater and soil
- 523 cubic yards treated during the demonstration

Regulatory Requirements/Cleanup Goals:
- The purpose of the demonstration was to evaluate the effectiveness of cometabolic air sparging to remove CAHs from groundwater; the technology was also evaluated against the MCLs for the target CAHs

Cometabolic Air Sparging at McClellan Air Force Base, OU A, Sacramento, CA (continued)

Results:

- In the saturated zone, CAH concentrations were reduced to near or below the MCLs after about 200 days of operation; reductions in the active zone were attributed to propane degradation and cometablism; volatilization was observed in the control zone and contributed to CAH removal
- In the vadose zone, after more than 500 days of operation, no CAH cometabolism through propane degradation was observed, indicating that propane-degrading bacteria were not stimulated during the demonstration; a possible reason for the lack of degradation was limited nitrogen in the vadose zone
- Methane was substituted for propane and was rapidly degraded; levels of CAH decreased after the addition of methane, suggesting cometabolic degradation by methanotrophs
- The propane was also degraded following the addition of methane, suggesting that either methane stimulated the direct degradation of the propane or that the propane was degraded cometabolically by the growth of methanotrophs in the vadose zone

Costs:

- The costs for the demonstration were $891,800, or $1,705 per cubic yard based on 523 cubic yards treated
- Projected full-scale costs were $465,500, or $161 per cubic yard based on 2,888 cubic yards treated
- Results of the cost analysis indicated that treatment duration and vadose zone depth had the greatest effect on unit treatment costs

Description:

The Environmental Security Technology Certification Program (ESTCP) supported an 18-month field study to investigate use of a cometabolic air sparging (CAS) process at McClellan Air Force Base (AFB). McClellan was placed on the EPA National Priorities List in 1987 and was designated as a SERDP National Test Site in 1993. A demonstration of cometabolic air sparging was conducted to evaluate the effectivness and costs of the technology to remove CAHs from the groundwater. Two test plots were used for the demonstration - one control plot using air injection only and one active plot where air and propane were injected to test cometabolic air sparging.

Results from the demonstration showed that, after 200 days of operation, CAHs in the saturated zone were reduced to near or below the MCLs. However, after 500 days of operation, propane degradation had not been observed in the vadose zone and there was no evidence of CAH cometabolism. Methane was substituted for the propane and was rapidly degraded, along with the propane, and levels of CAHs were further reduced. These results suggested that a possible lack of nitrogen in the vadose zone limited propane degradation and that the addition of methane either stimulated direct propane degradation or that propane was degraded cometabolically by methanotrophs. The overall performance showed that cometabolic air sparging using propane as the growth substrate was effective in the saturated zone but did not meet expectations on the vadose zone.

Anaerobic Compost Constructed Wetlands at the Clear Creek/Central City Superfund site, Burleigh Tunnel, Silver Plume, Colorado

Site Name:
Clear Creek/Central City Superfund site

Location:
Silver Plume, Colorado

Period of Operation:
Fall 1994 - Fall 1997

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Use of constructed wetlands for treatment of zinc in acid mine drainage

Cleanup Type:
Field demonstration

Contaminants:
Zinc

Waste Source:
Drainage from mine operations

Contacts:

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Technology:
Constructed wetlands systems (CWS)

- Excavated pits filled with organic matter; two cells constructed
- Cells constructed below grade in both upflow and downflow mode
- Both cells consisted of a 0.05-acre cell (pit) filled 4 feet deep with a mixture of an organic-rich compost (96 percent) and alfalfa hay (4 percent)
- Base of each cell made up of a gravel subgrade, a 16-ounce geofabric, a sand layer, a clay liner, and a high-density polyethylene liner
- Base separated from influent or effluent piping by a geonet
- Each cell designed for a flow of 7 gpm
- Metals removed through a combination of sorption, precipitation, and biological sulfate reduction

Type/Quantity of Media Treated:
Mine drainage

Regulatory Requirements/Cleanup Goals:
Not identified

Results:

- Upflow cell removed an average of 93 percent of zinc during the first year of operation, and 49 and 43 percent during the second and third years
- Downflow cell removed an average of 77 percent of zinc during the first year and 70 percent during the second year. During the final 6 months of operation, loss of permeability in the cell caused an increase in the retention time of the mine drainage in the cell. This resulted in a higher percentage (82 percent) of zinc removal

Costs:
No information was provided about the cost of this application.

Anaerobic Compost Constructed Wetlands at the Clear Creek/Central City Superfund site, Burleigh Tunnel, Silver Plume, Colorado (continued)

Description:
As part of the Superfund Innovative Technology Evaluation (SITE) Program, EPA evaluated CWS for removing high concentrations of zinc from mine drainage at Burleigh Tunnel in Silver Plume, Colorado. The system operated for three years and treated zinc in the mine drainage through sorption, sulfate reduction, and precipitation of zinc oxides, hydroxides, and carbonates. Organic-rich compost and alfalfa hay were placed two 0.05-acre, 4 ft deep cells (one upflow and one downflow). The cells were designed for a flow of 7 gpm.

Results from the upflow cell showed that the constructed wetlands system removed an average of 93 percent of zinc during the first year of operation, and 49 and 43 percent during the second and third years. The downflow cell removed an average of 77 percent of zinc during the first year and 70 percent during the second year. During the final 6 months of operation, the cell showed 82 percent zinc removal. No information was provided about the cost of this application. During the demonstration, it was noted that the cells can sometimes develop visibly obvious preferential pathways of flow. This was observed in the upflow cell in 1997, and was addressed by terminating flow to the preferred section, excavating the wetland substrate, and allowing installation of a cap on the influent line.

In Situ Chemical Reduction at the Marshall Space Flight Center, Source Area 2, Huntsville, Alabama

Site Name:
Marshall Space Flight Center

Location:
Huntsville, AL

Period of Operation:
July 2000 to ongoing (data available from July 2000 to March 2002)

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Field demonstration of *in situ* chemical reduction using injection and reactive barrier wall to treat groundwater contaminated with cVOCs at a site containing UXO

Cleanup Type:
Field demonstration

Contacts:

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Waste Source:
Historical solvent waste management practices from rocket engine testing operations

Contaminants:
Chlorinated volatile organics compounds (cVOCs)
- TCE in groundwater at concentrations as high as 72,800 ug/L

Type/Quantity of Media Treated:
Groundwater
- Approximately 55 pounds of contaminants were estimated to be located in the residuum groundwater at demonstration area

Technology:
In Situ Chemical Reduction
- *In situ* chemical reduction using a ZVI slurry (Ferox^{SM} process) with pneumatic fracturing was pilot tested at SA-2
- Pneumatic fracturing was performed using nitrogen gas injected into the ground at 120 pounds per square inch (psi). The gas was used to create preferential pathways in the low permeability, capillary fringe media above the rubble zone
- Following fracturing, ZVI powder was mixed with water under pressure to form a slurry; the slurry was injected into subsurface target intervals using the patented LAI^{SM} system; a specialized nozzle (capable of delivering the atomized fluids in up to a 360-degree pattern) was used to atomize the injected fluids to improve dispersal into the target zone
- 11,000 pounds of ZVI was injected to reduce 55 pounds of TCE; field ratio of iron to TCE by weight was 200:1; average slurry delivery pressure - 60 psi

Regulatory Requirements/Cleanup Goals:
- The objective of the pilot test was to evaluate the effectiveness of *in situ* chemical reduction using the ZVI Ferox^{SM} process to treat TCE in SA-2
- No specific cleanup targets were identified for the pilot test

In Situ Chemical Reduction at the Marshall Space Flight Center, Source Area 2, Huntsville, Alabama (continued)

Results:

- During the period from July 2000 to March 2002, the ZVI chemical reduction pilot test in SA-2 reduced the concentrations of TCE in two source area monitoring wells by 52 and 90%, respectively
- TCE concentrations were reduced during the first 13 months after injection and then began to show increases, possibly indicating rebound; MSFC plans to continue groundwater monitoring on a quarterly basis to evaluate the potential for rebound
- As of March 2002, TCE degradation products, including DCE, VC, and chloride, were identified in the groundwater, and the redox potential for the groundwater changed to highly reducing conditions, indicating that the chemical reduction process was affecting groundwater quality

Costs:

- The cost to implement the pilot test was $27 per pound of ZVI injected
- The actual field demonstration portion of the test was approximately 70 percent of the total costs ($209,900), corresponding to about $19 per pound of ZVI injected

Description:

The Marshall Space Flight Center (MSFC) is a federal research and development facility located within the Redstone Arsenal (RSA) in Huntsville, Alabama. During the 1940's, RSA was used for manufacturing munitions and from 1949 to 1960 for developing rockets and guided missile systems. Since 1960, when the civilian rocketry and mission activities were transferred to the National Aeronautics and Space Administration (NASA), MSFC has been used to support the space program, including developing spacecraft and rocket engines. Historical solvent waste management practices from rocket engine testing operations at MSFC resulted in contamination of soil and groundwater at the facility, primarily with chlorinated volatile organic compounds (cVOCs). Site investigations identified five major cVOC plumes at MSFC along with 14 contaminant source areas that may act as continuing sources of groundwater contamination.

A pilot test of *in situ* chemical reduction technology was performed to assess the ability of the technology to treat dissolved TCE in the residuum groundwater beneath the Source Area 2 (SA-2) area. SA-2 was the location of a pond (CERCLA Site MSFC-005) that had received TCE from engine cleaning operations and had overflowed through a concrete trough to surrounding soils. The presence of unexploded ordnance (UXO) within the subsurface beneath the SA-2 area affected the design and operation of the pilot test; clearance of all subsurface sampling, injection and permanent groundwater monitoring points was required the injection of ZVI slurry in many areas having the highest groundwater concentrations was limited. Through March 2002, the ZVI chemical reduction pilot test in SA-2 reduced the concentrations of TCE in two source area monitoring wells by 52 and 90%, respectively, and other parameters indicate that chemical reduction is occurring. Because of concern about possible rebound, MSFC plans to continue groundwater monitoring on a quarterly basis to evaluate the potential for rebound.

In Situ Chemical Oxidation at Two Drycleaner Sites, Hutchinson, Kansas and Jacksonville, Florida

Site Name:
Multiple (2) Dry Cleaner Sites - *In Situ* Chemical Oxidation

Location:
- Indeeda Cleaners, Hutchinson, KS
- Swift Cleaners, Jacksonville, FL

Period of Operation:
Ineeda Cleaners - August 1998 - Not provided
Swift Cleaners - December 2000 - April 2002

Cleanup Authority:
State

Purpose/Significance of Application:
Use of *in situ* oxidation technologies for remediation of chlorinated solvents in groundwater at drycleaner facilities

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents
- Both sites were contaminated with PCE and TCE Concentrations varied at the two sites, ranging from 4,400 to 10,000 µg/L for PCE, and 24 to 382 µg/L for TCE
- Ineeda Cleaners also reported the presence of cis 1,2-DCE at 134 µg/L
- Both sites reported that DNAPLs were present.

Waste Source:
Waste and wastewater from drycleaning operations

Contacts:
Varied by site

Technology:
In situ chemical oxidation
- At Ineeda Cleaners, three KVA C-Sparger wells were installed to surround the main groundwater contamination area, and ozone was injected to oxidize contaminants.
- At Swift Cleaners, 400 to 600 gallons of 14%-15% hydrogen peroxide (plus catalyst) were injected in two separate areas, IA and IB. In area IA, 12 wells were used, with 2 injections per well. In area IB, 13 wells were used, with 2 injections per well. For both areas, the radius of influence was 7.5 ft. During a third injection in areas IA and IB, a total of 600 gallons of 15% hydrogen peroxide was injected in 11 wells.

Type/Quantity of Media Treated:
Groundwater
- Reported plume areas ranged from 300,000 ft^2 to 12,000,000 ft^2, and reported plume depths ranged from 50 to 56 ft bgs. For Swift Cleaners, the reported actual treatment area was 4,500 ft^2 and the reported actual treatment depth ranged from 35 to 45 feet. This information was not provided for Ineeda Cleaners.

Regulatory Requirements/Cleanup Goals:
Cleanup goals were based on EPA MCLs, reported for Swift Cleaners as 3.0 µg/L for PCE and TCE; cleanup goals were not reported for Ineeda Cleaners.

Results:
- At Ineeda Cleaners, groundwater concentrations were not significantly reduced during the operation of the KVA system. The system experienced maintenance problems, which may have affected performance.
- At Swift Cleaners, contaminant levels were not reduced to below cleanup goals. First quarter sampling showed that PCE concentrations were reduced to below 200 µg/L. Second quarter sampling showed that several wells showed a rebound, with PCE concentrations rising to above the baseline level of 1,050 µg/L. Results of the third injection (in both areas IA and IB) continued to show contaminant rebound.

Costs:
Reported design and implementation costs:
- Ineeda Cleaners: $100,900
- Swift Cleaners: $245,000

In Situ Chemical Oxidation at Two Drycleaner Sites, Hutchinson, Kansas and Jacksonville, Florida (continued)

Description:
In situ chemical oxidation was conducted at two drycleaner sites contaminated with chlorinated solvents from drycleaning operations with TCE and PCE as the primary contaminants in groundwater. The concentration of PCE and TCE varied between the two sites, ranging from 4,400 to 10,000 µg/L for PCE, and 24 to 382 µg/L for TCE. Reported plume areas ranged from 300,00 ft^2 to 12,000,000 ft^2, and reported plume depths ranged from 50 to 56 bgs. The remediation involved *in situ* chemical oxidation at full-scale at both sites.

At one site, ozone was injected into the subsurface, and at the other site, hydrogen peroxide and catalyst (Fenton's chemistry) were injected into the subsurface. The cleanup goal of EPA MCLs was not met at either site after up to 3 rounds of injection. At Ineeda Cleaners, this was attributed to problems with the KVA C-Sparger wells. At Swift Cleaners, rebound concentrations of PCE were observed after three injection events. Subsequent remediation efforts will be conducted at this site in three additional phases proceeding downgradient.

In Situ Chemical Oxidation (ISCO) Treatment of DNAPL Source Zone at Launch Complex 34, Cape Canaveral Air Force Station, Florida

Site Name:
Cape Canaveral Air Force Station, Launch Complex 34

Location:
Cape Canaveral, Florida

Period of Operation:
September 8, 1999 to April 17, 2000

Cleanup Authority:
Not Provided

Purpose/Significance of Application:
Field demonstration of ISCO to treat a DNAPL source area

Cleanup Type:
Field Demonstration

Contaminants:
Halogenated VOCs
- TCE - Estimated mass of 6,122 kg in test plot
- DNAPL - 5,039 kg of the TCE mass was estimated to be DNAPL

Waste Source:
Wastes from rocket engine and parts cleaning operations

Contacts:

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Technology:
In Situ Chemical Oxidation (ISCO)
- Field demonstration of ISCO - source zone test plot was 75 ft by 50 ft by 45 ft deep
- A total of 842,985 gal of permanganate solution (1.4 to 2 percent) was injected into the test plot in 3 phases over a period of 8 months; vendor designed and supplied a continuous mix and automated feed system for the demonstration
- First injection September to October 1999 - a total of 304,763 gallons of solution were injected, first into the upper unit, then into the middle unit, followed by the lower unit; a GeoProbe equipped with a specially designed tip was used to inject the solution; the estimated radius of influence was 10-12 ft; however, local heterogeneities limited oxidant distribution in some areas
- The second (November 1999) and third (March to April 2000) injections - focused only on those portions of the plot where interim monitoring results showed that the area had not received sufficient oxidant during the previous cycle; a total of 87,483 gallons of solution were injected during the second cycle and 450,739 gallons during the third cycle
- One major system interruption occurred during the demonstration - hurricane in September 1999

Type/Quantity of Media Treated:
Groundwater
- Test plot size - 75 ft by 50 ft by 45 ft

Regulatory Requirements/Cleanup Goals:
- The objective of the field demonstration was to reduce the contaminant mass by 90 percent

Results:
- The mass of TCE and DNAPL was reduced by 77 percent and 76 percent, respectively; while less than the target of 90 percent, the removal percentage was considered to be significant for the technology
- The highest level of removal was observed in the upper sand zone, indicating that the oxidant distribution was most efficient in the coarser soils in this zone
- TCE and DNAPL removal pathways included destruction by oxidation, migration to the surrounding aquifer, and migration to the vadose zone and atmosphere
- Dissolved TCE levels decreased in most parts of the test plot, with several monitoring wells showing levels below the MCL of 5 µg/L

In Situ Chemical Oxidation (ISCO) Treatment of DNAPL Source Zone at Launch Complex 34, Cape Canaveral Air Force Station, Florida (continued)

Costs:

- The total cost for the field demonstration was approximately $1 million, including costs for design, procurement, equipment and oxidant, mobilization/demobilization, and process monitoring
- The vendor indicated that about 15 percent of the cost was due to use of the technology at a demonstration rather than a full-scale application

Description:

A 1998 site investigation at the Cape Canaveral Air Force Station in Florida identified a large DNAPL source at Launch Complex 34. Historical activities at the site included discharging wastes generated from rocket engine and parts cleaning operations into discharge pits. Chlorinated solvents, including TCE, were used in these cleaning operations. The Interagency DNAPL Consortium selected this site for demonstrating DNAPL treatment technologies. One of the technologies tested was *in situ* chemical oxidation (ISCO).

A field demonstration of ISCO was performed from September 8, 1999 to April 17, 2000, with the post- demonstration monitoring performed through February 2001. During the 8-month demonstration, more than 840,000 gallons of permanganate solution were injected in three phases. Following the first injection, monitoring results showed that local heterogeneities limited oxidant distribution in some areas. A second and third phase of injections were performed, focusing on those portions of the plot where interim monitoring results showed that the area had not received sufficient oxidant during the previous cycle. ISCO reduced the concentrations of dissolved TCE in the groundwater and reduced the mass of TCE and DNAPL in the test plot by 77 percent and 76 percent, respectively. While less than the target of 90 percent, the removal percentage was considered to be significant for the technology. The best distribution of the oxidant occurred in the upper sandy soils; distribution of oxidant was more difficult in finer-grained soils. Local geologic heterogeneities and native organic matter content may limit oxidant distribution in some regions.

Permeable Reactive Barrier Longevity and Hydraulic Performance at Four DoD Sites

Site Name:
Multiple DoD Sites

Location:
Moffett Field, CA
Lowry AFB, CO
Seneca Army Depot, NY
Dover AFB, DE

Period of Operation:
Varies (e.g., Moffett and Seneca ongoing through 2001)

Cleanup Authority:
Not identified

Purpose/Significance of Application:
To evaluate long-term performance and hydraulic conductivity of PRBs in different hydrogeologic settings and with varying measurement techniques

Cleanup Type:
Field demonstration

Contaminants:
Halogenated Volatiles

Waste Source:
Not provided

Contacts:

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Technology:
Permeable Reactive Barrier (PRB)
- Funnel and gate designs were used at Moffett, Lowry, and Dover
- Continuous wall was used at Seneca
- Moffett: gate 10 ft wide; granular iron supplied by Peerless Metal Powders, Inc.
- Lowry: iron supplied by Master Builders Supply
- Seneca: 600 ft long continuous trench, 1 ft wide, keyed into competent shale bedrock 5-10 ft bgs; barrier consists of 50:50 mixture of sand and iron
- Dover: interlocking sheet piles used for funnel and caisson excavations filled with iron constitute 2 gates

Type/Quantity of Media Treated:
Groundwater
Moffett: Hydraulic conductivity of channel sand and gravel - 150 ft/day, porosity - 0.30
Lowry: Silty-sand to sand and gravel unconfined aquifer over weathered claystone bedrock; some heterogeneity
Seneca: Fractured shale and overlying glacial till; unconfined aquifer
Dover: Unconfined silty sand deposits overlying a thick clayey confining layer; fairly homogeneous; hydraulic gradient fairly low (0.002) and variable

Regulatory Requirements/Cleanup Goals:
The objectives for the demonstration were to evaluate longevity and hydraulic performance of PRBs at sites with varying hydogeologic conditions; no specific cleanup goals were identified

Results:
- Longevity was evaluated at Moffett Field and Lowry AFB using accelerated column tests, looking at changes in the reaction rates (half lives) of contaminants when the iron was exposed to many pore volumes of contaminated groundwater; actual groundwater from the two sites was used
- The PRBs at Moffett and Lowry had projected lifetimes of approximately 30 years, based on the time period over which the reactivity of the iron would decline by a factor of two
- Hydraulic performance was evaluated at all four sites based on a characterization of the flow regime around existing field barriers, and on results from groundwater modelling of the factors that determine flow, looking at groundwater capture zones and residence times
- The hydraulic evaluation showed that careful water level measurements combined with groundwater modeling provided the best results, sometimes contrasting with results from direct flow measurements

Permeable Reactive Barrier Longevity and Hydraulic Performance at Four DoD Sites (continued)

Costs:

- A present value analysis of the projected costs for a PRB and comparable pump and treat system showed that it would take approximately 7 to 10 years to obtain a payback on the initial capital investment in a PRB
- Cost for field demonstration of PRB at Moffett was reported as $802,375, consisting of $652,375 in capital costs and $150,000 in O&M costs (based on 5 monitoring events)
- Cost for field demonstration of PRB at Dover was reported as $739,000, consisting of $365,000 for pre-construction activities and $374,000 for PRB construction

Description:

Naval Air Station (NAS) Moffett Field and Lowry Air Force Base (AFB) are former DoD operational facilities that have groundwater contaminated with halogenated volatile compounds. Both sites had installed PRBs and had historical information available about field operation of the PRBs. The sites were evaluated to determine expected longevity of the PRBs, including groundwater geochemistry monitoring, iron core collection and analysis, geochemical modeling, and accelerated column tests. These tests showed that the reactivity of the iron declined with long-term exposure to groundwater and was related to the concentration of dissolved solids and rate of groundwater flow through the reactive media.

Hydraulic performance was evaluated for PRBs at Moffett Field, Lowry AFB, Seneca Army Depot, and Dover AFB. Moffett, Lowry, and Dover used funnel and gate configurations, while Seneca used a continuous trench design. The hydraulic performance was evaluated using water level measurements and slug tests, HydroTechnics™ flow sensors and colloidal borescope, and groundwater flow and solute transport modeling. Results showed that careful water level measurements combined with groundwater modeling provided the best results for hydraulic performance. These results sometimes contrasted with the results from direct flow measurements, possibly due to localized differences in groundwater flow conditions.

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EX SITU GROUNDWATER TREATMENT ABSTRACTS

Bi-functional Resin Groundwater Treatment at Paducah Gaseous Diffusion Plant, Kentucky

Site Name:
Paducah Gaseous Diffusion Plant

Location:
Kentucky

Period of Operation:
February to September 1999

Cleanup Authority:
Not provided

Purpose/Significance of Application:
Field demonstration of a bi-functional resin to treat groundwater contaminated with ^{99}Tc

Cleanup Type:
Field Demonstration

Contaminants:
Radionuclides
- Technetium (^{99}Tc); chemical form in oxygen-rich groundwater is the pertechnetate anion TcO^-_4
- Concentrations in groundwater ranged from 170 to 250 ng/L

Waste Source:
Disposal in lagoons and pits of wastes from processing uranium and plutonium

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Technology:
Ion Exchange - Bi-functional Resin (BiQuat)
- BiQuat anion-exchange resin - trihexylammonium and triethylammonium exchange sites; designated as resin D3696 by Purolite; resin had a mesh of -25/+40 and a total anion exchange capacity of 2.0 meq/g
- Field demonstration system consisted of a resin-filled column, 12 inches long by 5.25 inches in diameter; a contingent pump was used to pump water from the bottom to the top of the column at a rate of 2.5 gallons per minute
- Column was equipped with pressure gauges at the inlet and outlet and sampling ports at the inlet, outlet, and along the column at points 1/3 and 2/3 the length of the column

Type/Quantity of Media Treated:
Groundwater
- 840,000 gallons

Regulatory Requirements/Cleanup Goals:
- The purpose of the demonstration was to evaluate the effectiveness of BiQuat in treating groundwater contaminated with ^{99}Tc , including assessing breakthrough, residence time, and cost

Results:
- The performance of the resin was evaluated based on pertechnetate concentrations
- Breakthrough - no breakthrough was observed in the column effluent; complete breakthrough was observed at the first sampling port on the column (1/3 column length), and 20 percent breakthrough was observed at the second sampling port (2/3 column length)
- Residence time was determined to be 27 seconds which was considered to be a very short time for complete capture of the pertechnetate
- Results also showed that the resin was particularly effective in removing low levels of pertechnetate (in the nmol/L range); BiQuat was determined to be approximately fives times more effective than the commercial Purolite A-520E resin for Tc removal

Bi-functional Resin Groundwater Treatment at Paducah Gaseous Diffusion Plant, Kentucky (continued)

Costs:

- Information about the capital costs, operating and maintenance costs, and costs of scale-up were not available
- The estimated cost of the BiQuat resin was $1,000 per cubic foot; this cost is approximately five times the cost of the commercial Purolite A-520E resin for Tc removal; however, because the BiQuat resin is about fives times more efficient than Purolite A-520E, the costs would be approximately the same for the two resins
- Resin regeneration is economically desirable, given the relatively high cost of BiQuat

Description:

At DOE's Paducah Gaseous Diffusion Plant in Kentucky, wastewater from processing uranium and plutonium were discharged to lagoons and pits. The wastewater was frequently contaminated with Tc, and a contaminant plume is present in the sandy aquifer at the site below the vadose zone. The Tc is present in the groundwater as the pertechnetate anion, which is highly mobile. New bi-functional anion exchange resins that are highly selective for pertechnetate have been designed and are being tested as part of a research project at the Oak Ridge National Laboratory and the University of Tennessee.

A field demonstration was performed using the BiQuat anion-exchange resin, a resin containing trihexylammonium and triethylammonium exchange sites. The demonstration system included a 12 inch resin packed column with a flow rate of about 2.5 gallons per minute. The demonstration showed that the resin was effective in removing pertechnetate, especially at low levels, and that the resin was five times more efficient than the best competing resin (Purolite A-520). However, the cost of the BiQuat resin is relatively high (about $1,000 per cubic foot). A large-scale application of the technology would be needed to make the use of the resin commercially viable.

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APPENDIX A

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EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Soil Vapor Extraction (36 Projects)					
Basket Creek Surface Impoundment Site, GA	SVE	Soil	TCE; Volatiles-Halogenated; Ketones; Volatiles-Nonhalogenated; Heavy Metals	1992	1997
Camp Lejeune Military Reservation, Site 82, Area A, NC	SVE	Soil	BTEX; PCE; TCE; Volatiles-Halogenated; Volatiles-Nonhalogenated	1995	1998
Commencement Bay, South Tacoma Channel Well 12A Superfund Site, WA	SVE	Soil; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	1992	1995
Davis-Monthan AFB, Site ST-35, AZ	SVE	Soil	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1995	1998
Defense Supply Center Richmond, OU 5, VA	SVE (Field Demonstration)	Soil	PCE; TCE; Volatiles-Halogenated	1992	1998
Fairchild Semiconductor Corporation Superfund Site, CA	SVE	Soil	PCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1989	1995
Fort Greely, Texas Tower Site, AK	SVE; Air Sparging; Bioremediation (in situ) Enhanced Bioremediation	Soil; Groundwater	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1994	1998
Fort Lewis, Landfill 4, WA	SVE; Air Sparging	Soil	TCE; DCE; Volatiles-Halogenated; Heavy Metals	1994	1998

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Fort Richardson, Building 908 South, AK	SVE	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated; Volatiles-Halogenated	1995	1998
Hastings Groundwater Contamination Superfund Site, Well Number 3 Subsite, NE	SVE	Soil	TCE; Volatiles-Halogenated	1992	1995
Holloman AFB, Sites 2 and 5, NM	SVE	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1994	1998
Intersil/Siemens Superfund Site, CA	SVE	Soil	TCE; Volatiles-Halogenated	1988	1998
Luke Air Force Base, North Fire Training Area, AZ	SVE	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated; Ketones	1990	1995
McClellan Air Force Base, Operable Unit D, Site S, CA	SVE (Field Demonstration)	Soil	PCE; TCE; DCE; Volatiles-Halogenated	1993	1995
Multiple (3) Drycleaner Sites - SVE/Air Sparging, Various Locations	SVE; Air Sparging	Soil; Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	Various years - starting 1995	2003
Multiple (3) Drycleaner Sites - SVE/MNA, Various Locations	SVE; Monitored Natural Attenuation; Pump and Treat	Soil; Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	Various years - starting 1996	2003
Multiple (6) Drycleaner Sites, Various Locations	SVE	Soil; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	Various years - starting 1992	2003

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Multiple (7) Dry Cleaner Sites	SVE; Pump and Treat	Soil; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	Various years - starting 1998	Various years - 2001, 2002
Multiple (7) Dry Cleaner Sites - P&T/SVE/MPE, Various Locations	SVE; Multi Phase Extraction; Pump and Treat	Soil; Groundwater; DNAPLs; Off-gases	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	Various years - starting 1991	2003
NAS North Island, Site 9, CA	SVE (Photolytic Destruction) (Field Demonstration)	Soil	PCE; TCE; DCE; BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated	1997	1998
Patrick Air Force Base, Active Base Exchange Service Station, FL	SVE (Biocube™) (Field Demonstration)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1994	2000
Patrick Air Force Base, Active Base Exchange Service Station, FL	SVE (Internal Combustion Engine) (Field Demonstration)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1993	2000
Rocky Mountain Arsenal Superfund Site (Motor Pool Area - Operable Unit #18), CO	SVE	Soil	TCE; Volatiles-Halogenated	1991	1995
Sacramento Army Depot Superfund Site, Burn Pits Operable Unit, CA	SVE	Soil	PCE; TCE; DCE; Volatiles-Halogenated	1994	1997
Sacramento Army Depot Superfund Site, Tank 2 (Operable Unit #3), CA	SVE	Soil	Ketones; BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated	1992	1995

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Sand Creek Industrial Superfund Site, Operable Unit 1, CO	SVE	Soil; LNAPLs	PCE; TCE; Volatiles-Halogenated; Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1993	1997
Seymour Recycling Corporation Superfund Site, IN	SVE; Containment - Caps; Bioremediation (in situ) Enhanced Bioremediation	Soil	PCE; TCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1992	1998
Shaw AFB, OU 1, SC	SVE; Free Product Recovery	Soil; Groundwater; LNAPLs	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1995	1998
SMS Instruments Superfund Site, NY	SVE	Soil	Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1992	1995
Stamina Mills Superfund Site, RI	SVE; Multi Phase Extraction (Field Demonstration)	Soil; Off-gases	TCE; Volatiles-Halogenated	1999	2001
Tyson's Dump Superfund Site, PA	SVE	Soil	PCE; TCE; DCE; Volatiles-Halogenated	1988	1998
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH	SVE; Chemical Oxidation/Reduction (in situ); Solidification/Stabilization; Thermal Treatment (in situ) (Field Demonstration)	Soil	TCE; DCE; Volatiles-Halogenated	1992	1997
U.S. Department of Energy, Savannah River Site, SC	SVE (Flameless Thermal Oxidation) (Field Demonstration)	Soil; Off-gases	PCE; TCE; Volatiles-Halogenated	1995	1997

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
U.S. Department of Energy, Savannah River Site, SC, and Sandia, NM	SVE; In-Well Air Stripping; Bioremediation (in situ) ALL; Drilling (Field Demonstration)	Soil; Groundwater	Volatiles-Halogenated	1988	2000
Vandenberg Air Force Base, Base Exchange Service Station, CA	SVE (Resin Adsorption) (Field Demonstration)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1994	2000
Verona Well Field Superfund Site (Thomas Solvent Raymond Road - Operable Unit #1), MI	SVE	Soil Light Non-aqueous Phase Liquids	Ketones; BTEX; Volatiles-Nonhalogenated; PCE; Volatiles-Halogenated	1988	1995
Other *In Situ* Soil/Sediment Treatment (35 Projects)					
Alameda Point, CA	Electrokinetics (Field Demonstration)	Soil	Heavy Metals	1997	2001
Argonne National Laboratory - West, Waste Area Group 9, OU 9-04, ID	Phytoremediation (Field Demonstration)	Soil	Heavy Metals	1998	2000
Avery Dennison, IL	Thermal Treatment (in situ)	Soil; DNAPLs	Volatiles-Halogenated	1999	2003
Beach Haven Substation, Pensacola, FL	Electrokinetics (Field Demonstration)	Soil	Arsenic	1998	2000
Brodhead Creek Superfund Site, PA	Thermal Treatment (in situ)	Soil; DNAPLs	PAHs; Semivolatiles-Nonhalogenated; BTEX; Volatiles-Nonhalogenated; Arsenic	1995	1998
Castle Airport, CA	Bioremediation (in situ) Bioventing (Field Demonstration)	Soil	BTEX; Volatiles-Nonhalogenated	1998	1999
Confidential Chemical Manufacturing Facility, IN	Thermal Treatment (in situ)	Soil; DNAPLs; Off-gases	PCE; TCE; DCE; Volatiles-Halogenated	1997	2003

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Crooksville/Roseville Pottery Area of Concern (CRPAC), OH	Solidification/Stabilization (Field Demonstration)	Soil	Heavy Metals	1998	2003
Dover Air Force Base, Building 719, DE	Bioremediation (in situ) Bioventing (Field Demonstration)	Soil	TCE; DCE; Volatiles-Halogenated	1998	2000
Eielson Air Force Base, AK	Bioremediation (in situ) Bioventing (Field Demonstration)	Soil	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1991	1995
Ensign-Bickford Company - OB/OD Area, CT	Phytoremediation	Soil	Heavy Metals	1998	2000
Former Mare Island Naval Shipyard, CA	Thermal Treatment (in situ) (Field Demonstration)	Soil	PCBs; Semivolatiles-Halogenated	1997	2000
Fort Richardson Poleline Road Disposal Area, OU B, AK	Thermal Treatment (in situ); SVE (Field Demonstration)	Soil	PCE; TCE; Volatiles-Halogenated	1997	2000
Hill Air Force Base, Site 280, UT	Bioremediation (in situ) Bioventing	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1990	1995
Hill Air Force Base, Site 914, UT	Bioremediation (in situ) Bioventing; SVE	Soil	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1988	1995
Idaho National Engineering and Environmental Laboratory, ID	Bioremediation (in situ) Bioventing (Field Demonstration)	Soil	Volatiles-Halogenated	1996	2000
Koppers Co. (Charleston Plant) Ashley River Superfund Site, SC	Solidification/Stabilization	Sediment; DNAPLs	PAHs; Semivolatiles-Nonhalogenated	2001	2003
Lowry Air Force Base, CO	Bioremediation (in situ) Bioventing	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1992	1995
Magic Marker, NJ and Small Arms Firing Range (SAFR) 24, NJ	Phytoremediation (Field Demonstration)	Soil	Heavy Metals	Magic Marker - 1997; Fort Dix - 2000	2002
Missouri Electric Works Superfund Site, MO	Thermal Treatment (in situ) (Field Demonstration)	Soil	PCBs; Semivolatiles-Halogenated	1997	1998

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Multiple Air Force Test Sites, Multiple Locations	Bioremediation (in situ) Bioventing (Field Demonstration)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1992	2000
Naval Air Weapons Station Point Mugu Site 5, CA (USAEC)	Electrokinetics (Field Demonstration)	Soil; Sediment	Heavy Metals	1998	2000
Naval Air Weapons Station Point Mugu Site 5, CA (USEPA)	Electrokinetics (Field Demonstration)	Soil	Heavy Metals	1998	2000
Paducah Gaseous Diffusion Plant (PGDP) Superfund Site, KY	Lasagna™	Soil	TCE; Volatiles-Halogenated	1999	2003
Parsons Chemical/ETM Enterprises Superfund Site, MI	Vitrification (in situ)	Soil; Sediment	Pesticides/Herbicides; Semivolatiles-Halogenated; Heavy Metals; Dioxins/Furans	1993	1997
Portsmouth Gaseous Diffusion Plant, X-231A Site, Piketon, OH	Fracturing (Field Demonstration)	Soil; Groundwater	TCE; Volatiles-Halogenated	1996	2001
Sandia National Laboratories, Unlined Chromic Acid Pit, NM	Electrokinetics (Field Demonstration)	Soil	Heavy Metals	1996	2000
Savannah River Site 321-M Solvent Storage Tank Area, GA	Thermal Treatment (in situ) (Field Demonstration)	Soil; DNAPLs	PCE; TCE; Volatiles-Halogenated	2000	2003
Twin Cities Army Ammunition Plant, MN	Phytoremediation (Field Demonstration)	Soil	Heavy Metals; Arsenic	1998	2000
White Sands Missile Range, SWMU 143, NM	Chemical Oxidation/Reduction (in situ) (Field Demonstration)	Soil	Heavy Metals	1998	2000
U.S. Department of Energy, Hanford Site, WA, Oak Ridge (TN) and Others	Vitrification (in situ)	Soil; Sludge; Debris/Slag/ Solid	Pesticides/Herbicides; Heavy Metals; Arsenic; Dioxins/Furans; Semivolatiles-Halogenated PCBs; Radioactive Metals	Not Provided	1997
U.S. Department of Energy, Multiple Sites	Drilling (Field Demonstration)	Soil; Sediment	-	1992	1997

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
U.S. Department of Energy, Paducah Gaseous Diffusion Plant, KY	Lasagna™ (Field Demonstration)	Soil; Groundwater	TCE; Volatiles-Halogenated	1995	1997
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH and Other Sites	Fracturing (Field Demonstration)	Soil; Groundwater; DNAPLs	TCE; Volatiles-Halogenated	1991	1997
U.S. Department of Energy, Savannah River Site, SC, and Hanford Site, WA	Thermal Treatment (in situ) (Field Demonstration)	Soil; Sediment	PCE; TCE; Volatiles-Halogenated	1993	1997
Incineration (on-site) (18 Projects)					
Baird and McGuire, MA	Incineration (on-site)	Soil; Sediment	Dioxins/Furans; Semivolatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated; Arsenic; Heavy Metals; Volatiles-Halogenated	1995	1998
Bayou Bonfouca, LA	Incineration (on-site)	Soil; Sediment	PAHs; Semivolatiles-Nonhalogenated	1993	1998
Bridgeport Refinery and Oil Services, NJ	Incineration (on-site)	Soil; Debris/Slag/Solid; Sediment; Organic Liquids; Sludge	PCBs; Semivolatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Heavy Metals; Volatiles-Halogenated	1991	1998
Celanese Corporation Shelby Fiber Operations, NC	Incineration (on-site)	Soil; Sludge	PAHs; Semivolatiles-Nonhalogenated; TCE; Volatiles-Halogenated; Volatiles-Nonhalogenated; Heavy Metals; BTEX	1991	1998

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Coal Creek, WA	Incineration (on-site)	Soil	PCBs; Semivolatiles-Halogenated; Heavy Metals	1994	1998
Drake Chemical Superfund Site, Operable Unit 3, Lock Haven, PA	Incineration (on-site)	Soil	Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1998	2001
FMC Corporation - Yakima, WA	Incineration (on-site)	Soil; Debris/Slag/ Solid	Pesticides/Herbicides; Semivolatiles-Halogenated; Heavy Metals	1993	1998
Former Nebraska Ordnance Plant - OU 1, NE	Incineration (on-site)	Soil; Debris/Slag/ Solid	Explosives/Propellants	1997	1998
Former Weldon Springs Ordnance Works, OU 1, MO	Incineration (on-site)	Soil; Debris/Slag/ Solid	Explosives/Propellants; Heavy Metals; PCBs; Semivolatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated	1998	2000
MOTCO, TX	Incineration (on-site)	Soil; Sludge; Organic Liquids	PCBs; Semivolatiles-Nonhalogenated; Heavy Metals; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1990	1998
Old Midland Products, AR	Incineration (on-site)	Soil; Sludge	Semivolatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated; Volatiles-Nonhalogenated; Volatiles-Halogenated	1992	1998

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Petro Processors, LA	Incineration (on-site)	Organic Liquids; DNAPLs	PAHs; Semivolatiles-Nonhalogenated; Heavy Metals; Volatiles-Halogenated	1994	1998
Rocky Mountain Arsenal, CO	Incineration (on-site)	Organic Liquids	Pesticides/Herbicides; Heavy Metals; Arsenic	1993	1998
Rose Disposal Pit, MA	Incineration (on-site)	Soil	PCBs; Semivolatiles-Halogenated; TCE; Volatiles-Halogenated; Volatiles-Nonhalogenated	1994	1998
Rose Township Dump, MI	Incineration (on-site)	Soil	PCBs; Semivolatiles-Halogenated; Heavy Metals; BTEX; Volatiles-Nonhalogenated; Semivolatiles-Nonhalogenated; PAHs; Ketones	1992	1998
Sikes Disposal Pits, TX	Incineration (on-site)	Soil; Debris/Slag/Solid	PAHs; Semivolatiles-Nonhalogenated; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1992	1998
Times Beach, MO	Incineration (on-site)	Soil; Debris/Slag/Solid	Dioxins/Furans; Semivolatiles-Halogenated	1996	1998
Vertac Chemical Corporation, AR	Incineration (on-site)	Debris/Slag/Solid; Organic Liquids	Dioxins/Furans; Semivolatiles-Halogenated; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1992	1998

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Thermal Desorption (28 Projects)					
Anderson Development Company Superfund Site, MI	Thermal Desorption (ex situ)	Soil; Sludge	PAHs; Semivolatiles-Nonhalogenated; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Heavy Metals	1992	1995
Arlington Blending and Packaging Superfund Site, TN	Thermal Desorption (ex situ)	Soil	Pesticides/Herbicides; Semivolatiles-Halogenated; Arsenic	1996	2000
Brookhaven National Laboratory (BNL), NY	Thermal Desorption (ex situ) (Field Demonstration)	Soil	Heavy Metals	Not provided	2003
Cape Fear Superfund Site, NC	Thermal Desorption (ex situ)	Soil	PAHs; Semivolatiles-Nonhalogenated; Arsenic; Heavy Metals; Volatiles-Nonhalogenated; BTEX	1998	2002
FCX Washington Superfund Site, NC	Thermal Desorption (ex situ)	Soil	Pesticides/Herbicides; Semivolatiles-Halogenated	1995	1998
Fort Lewis, Solvent Refined Coal Pilot Plant (SRCPP), WA	Thermal Desorption (ex situ)	Soil	PAHs; Semivolatiles-Nonhalogenated	1996	1998
Industrial Latex Superfund Site, NJ	Thermal Desorption (ex situ)	Soil; Off-gases	Pesticides/Herbicides; Semivolatiles-Halogenated; PAHs; PCBs; Arsenic	1999	2003
Letterkenny Army Depot Superfund Site, K Areas, OU1, PA	Thermal Desorption (ex situ)	Soil	TCE; Volatiles-Halogenated; Heavy Metals	1993	2000

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Lipari Landfill, Operable Unit 3, NJ	Thermal Desorption (ex situ)	Soil	TCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Arsenic; Heavy Metals; Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1994	2002
Longhorn Army Ammunition Plant, Burning Ground No. 3, TX	Thermal Desorption (ex situ)	Soil	TCE; Volatiles-Halogenated	1997	2000
McKin Superfund Site, ME	Thermal Desorption (ex situ)	Soil	BTEX; Volatiles-Nonhalogenated; PAHs; Semivolatiles-Nonhalogenated	1986	1995
Metaltec/Aerosystems Superfund Site, Franklin Borough, NJ	Thermal Desorption (ex situ)	Soil	TCE; DCE; Volatiles-Halogenated; Heavy Metals	1994	2001
Naval Air Station Cecil Field, Site 17, OU 2, FL	Thermal Desorption (ex situ)	Soil	BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated	1995	1998
New Bedford Harbor Superfund Site, New Bedford, MA	Thermal Desorption (ex situ) (Field Demonstration)	Sediment	PCBs; Semivolatiles-Halogenated	1996	2001
Outboard Marine Corporation Superfund Site, OH	Thermal Desorption (ex situ)	Soil; Sediment	PCBs; Semivolatiles-Halogenated	1992	1995
Port Moller Radio Relay Station, AK	Thermal Desorption (ex situ)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1995	1998
Pristine, Inc. Superfund Site, OH	Thermal Desorption (ex situ)	Soil	Pesticides/Herbicides; PAHs; Semivolatiles-Nonhalogenated; Heavy Metals	1993	1995

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Reich Farm, Pleasant Plains, NJ	Thermal Desorption (ex situ)	Soil	Volatiles-Halogenated; Volatiles-Nonhalogenated; Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1994	2001
Reilly Industries Superfund Site, Operable Unit 3, IN	Thermal Desorption (ex situ)	Soil	PAHs; Semivolatiles-Nonhalogenated; BTEX; Volatiles-Nonhalogenated	1996	2002
Re-Solve, Inc. Superfund Site, MA	Thermal Desorption (ex situ)	Soil	PCBs; Semivolatiles-Halogenated; Ketones; BTEX; Volatiles-Nonhalogenated; TCE; Volatiles-Halogenated	1993	1998
Rocky Flats Environmental Technology Site, Mound Site, Golden, CO	Thermal Desorption (ex situ)	Soil	PCE; TCE; Volatiles-Halogenated	1997	2001
Rocky Flats Environmental Technology Site, Trenches T-3 and T-4, CO	Thermal Desorption (ex situ)	Soil; Debris/Slag/ Solid	TCE; Volatiles-Halogenated; Ketones; BTEX; Volatiles-Nonhalogenated; Radioactive Metals	1996	2000
Sand Creek Superfund Site, OU 5, CO	Thermal Desorption (ex situ)	Soil	Pesticides/Herbicides; Arsenic	1994	2000
Sarney Farm, Amenia, NY	Thermal Desorption (ex situ)	Soil	TCE; DCE; Volatiles-Halogenated; Ketones; BTEX; Volatiles-Nonhalogenated	1997	2001

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Site B (actual site name confidential), Western United States	Thermal Desorption (ex situ)	Soil; Off-gases	Pesticides/Herbicides; Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1995	2003
TH Agriculture & Nutrition Company Superfund Site, GA	Thermal Desorption (ex situ)	Soil	Pesticides/Herbicides	1993	1995
Waldick Aerospaces Devices Superfund Site, NJ	Thermal Desorption (ex situ)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated; PCE; Volatiles-Halogenated; Heavy Metals	1993	1998
Wide Beach Development Superfund Site, NY	Thermal Desorption (ex situ); Chemical Oxidation/Reduction (ex situ)	Soil	Semivolatiles-Halogenated; PCBs	1990	1995
Other *Ex Situ* Soil Treatment (32 Projects)					
Bonneville Power Administration Ross Complex, Operable Unit A, WA	Bioremediation (ex situ) Land Treatment	Soil	PAHs; Semivolatiles-Nonhalogenated; Semivolatiles-Halogenated	1994	1998
Brookhaven National Laboratory, NY	Physical Separation	Soil	Radioactive Metals	2000	2001
Brown Wood Preserving Superfund Site, FL	Bioremediation (ex situ) Land Treatment	Soil	PAHs; Semivolatiles-Nonhalogenated	1989	1995
Burlington Northern Superfund Site, MN	Bioremediation (ex situ) Land Treatment	Soil; Sludge	PAHs; Semivolatiles-Nonhalogenated	1986	1997
Dubose Oil Products Co. Superfund Site, FL	Bioremediation (ex situ) Composting	Soil	PAHs; Semivolatiles-Nonhalogenated; BTEX; Volatiles-Nonhalogenated; Semivolatiles-Halogenated	1993	1997

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Fort Greely, UST Soil Pile, AK	Bioremediation (ex situ) Land Treatment	Soil	BTEX; Volatiles-Nonhalogenated; Semivolatiles-Halogenated	1994	1998
Fort Polk Range 5, LA	Acid Leaching; Physical Separation (Field Demonstration)	Soil	Heavy Metals	1996	2000
French Ltd. Superfund Site, TX	Bioremediation (ex situ) Slurry Phase	Soil; Sludge	PAHs; Semivolatiles-Nonhalogenated; Volatiles-Halogenated; PCBs; Semivolatiles-Halogenated; Arsenic; Heavy Metals	1992	1995
Idaho National Environmental and Engineering Laboratory (INEEL), ID	Physical Separation	Soil	Radioactive Metals	1999	2001
Joliet Army Ammunition Plant, IL	Bioremediation (ex situ) Slurry Phase (Field Demonstration)	Soil	Explosives/Propellants	1994	2000
King of Prussia Technical Corporation Superfund Site, NJ	Soil Washing	Soil; Sludge	Heavy Metals	1993	1995
Los Alamos National Laboratory, NM	Physical Separation	Soil; Debris/Slag/ Solid	Radioactive Metals	1999	2000
Lowry Air Force Base, CO	Bioremediation (ex situ) Land Treatment	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1992	1995
Massachusetts Military Reservation, Training Range and Impact Area, Cape Cod, MA	Solidification/Stabilization	Soil	Heavy Metals	1998	2001
Naval Construction Battalion Center Hydrocarbon National Test Site, CA	Bioremediation (ex situ) Composting (Field Demonstration)	Soil	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1996	1998
New Bedford Harbor Superfund Site, New Bedford, MA	Solidification/Stabilization (Field Demonstration)	Sediment	PCBs; Semivolatiles-Halogenated	1995	2001

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
New Bedford Harbor Superfund Site, New Bedford, MA	Solvent Extraction (ex situ) (Field Demonstration)	Sediment	PCBs; Semivolatiles-Halogenated	1996	2001
New Bedford Harbor Superfund Site, New Bedford, MA	Vitrification (ex situ) (Field Demonstration)	Sediment	PCBs; Semivolatiles-Halogenated	1996	2001
Novartis Site, Ontario, Canada	Bioremediation (ex situ) Land Treatment (Field Demonstration)	Soil	Pesticides/Herbicides; Semivolatiles-Halogenated	1996	1998
Oak Ridge National Laboratory, TN	Vitrification (ex situ) (Field Demonstration)	Sludge	Heavy Metals; Radioactive Metals	1997	2000
Pantex Plant, Firing Site 5, TX	Physical Separation	Soil; Debris/Slag/ Solid	Radioactive Metals	1998	2000
Peerless Cleaners, WI; Stannard Launders and Dry Cleaners, WI	Bioremediation (ex situ) Composting	Soil	PCE; TCE; DCE; Volatiles-Halogenated; Semivolatiles-Nonhalogenated	Not Provided	2001
RMI Titanium Company Extrusion Plant, OH	Solvent Extraction (ex situ) (Field Demonstration)	Soil	Radioactive Metals	1997	2000
Sandia National Laboratories, ER Site 16, NM	Physical Separation	Soil	Radioactive Metals	1998	2000
Sandia National Laboratories, ER Site 228A, NM	Physical Separation	Soil	Radioactive Metals	1998	2000
Scott Lumber Company Superfund Site, MO	Bioremediation (ex situ) Land Treatment	Soil	PAHs; Semivolatiles-Nonhalogenated	1989	1995
Southeastern Wood Preserving Superfund Site, MS	Bioremediation (ex situ) Slurry Phase	Soil; Sludge	PAHs; Semivolatiles-Nonhalogenated	1991	1997
Sparrevohn Long Range Radar Station, AK	Solvent Extraction (ex situ)	Soil	PCBs; Semivolatiles-Halogenated	1996	1998
Stauffer Chemical Company, Tampa, FL	Bioremediation (ex situ) Composting (Field Demonstration)	Soil	Pesticides/Herbicides	1997	2001

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Tonapah Test Range, Clean Slate 2, NV	Physical Separation	Soil; Debris/Slag/ Solid	Radioactive Metals	1998	2000
Umatilla Army Depot Activity, OR	Bioremediation (ex situ) Composting (Field Demonstration)	Soil	Explosives/Propellants	1992	1995
Umatilla Army Depot Activity, OR	Bioremediation (ex situ) Composting	Soil	Explosives/Propellants	1994	1997
Pump and Treat (50 Projects)					
Amoco Petroleum Pipeline, MI	Pump and Treat; Air Sparging	Groundwater; LNAPLs	BTEX; Volatiles-Nonhalogenated	1988	1995
Baird and McGuire Superfund Site, MA	Pump and Treat	Groundwater	BTEX; Volatiles-Nonhalogenated; PAHs; Semivolatiles-Nonhalogenated; Pesticides/Herbicides; Semivolatiles-Halogenated	1993	1998
Bofors Nobel Superfund Site, OU 1, MI	Pump and Treat	Groundwater	BTEX; Volatiles-Nonhalogenated; Semivolatiles-Halogenated; Volatiles-Halogenated; Semivolatiles-Nonhalogenated	1994	1998
Charnock Wellfield, Santa Monica, CA	Pump and Treat; Chemical Oxidation/Reduction (ex situ) (Field Demonstration)	Drinking Water	MTBE; Volatiles-Nonhalogenated	1998	2001
City Industries Superfund Site, FL	Pump and Treat	Groundwater	BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated; Ketones; Semivolatiles-Nonhalogenated	1994	1998
Coastal Systems Station, AOC 1, FL	Pump and Treat (Field Demonstration)	Groundwater	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated; Heavy Metals	1997	1998

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Commencement Bay, South Tacoma Channel Superfund Site, WA	Pump and Treat; SVE	Groundwater; Soil; DNAPLs; LNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	1998	2001
Commencement Bay, South Tacoma Channel Well 12A Superfund Site, WA	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1988	1995
Des Moines TCE Superfund Site, OU 1, IA	Pump and Treat	Groundwater	TCE; DCE; Volatiles-Halogenated	1987	1998
Former Firestone Facility Superfund Site, CA	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1986	1998
Ft. Drum, Fuel Dispensing Area 1595, NY	Pump and Treat; Free Product Recovery	Groundwater; LNAPLs	BTEX; Volatiles-Nonhalogenated	1992	1995
Fort Lewis Logistics Center, WA	Pump and Treat	Groundwater	TCE; DCE; Volatiles-Halogenated	1995	2000
JMT Facility RCRA Site (formerly Black & Decker RCRA Site), NY	Pump and Treat	Groundwater	TCE; DCE; Volatiles-Halogenated	1988	1998
Keefe Environmental Services Superfund Site, NH	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1993	1998
King of Prussia Technical Corporation Superfund Site, NJ	Pump and Treat	Groundwater	BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated Heavy Metals	1995	1998

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Lacrosse, KS	Pump and Treat	Drinking Water	BTEX; Petroleum Hydrocarbons; MTBE; Volatiles-Nonhalogenated	1997	2001
Langley Air Force Base, IRP Site 4, VA	Pump and Treat	Groundwater; LNAPLs	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1992	1995
LaSalle Electrical Superfund Site, IL	Pump and Treat	Groundwater	PCBs; Semivolatiles-Halogenated; TCE; DCE; Volatiles-Halogenated	1992	1998
Lawrence Livermore National Laboratory (LLNL) Site 300 - General Services Area (GSA) Operable Unit, CA	Pump and Treat	Groundwater; Soil; DNAPLs	TCE; Volatiles-Halogenated	1991	1998
Marine Corps Base, Campbell Street Fuel Farm, Camp Lejeune, NC	Pump and Treat	Groundwater; Soil	BTEX; Volatiles-Nonhalogenated	1996	2001
Marine Corps Base, OU 1 and 2, Camp Lejeune, NC	Pump and Treat	Groundwater	PCBs; Semivolatiles-Nonhalogenated; Pesticides/Herbicides; Heavy Metals; BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated	1995	2001
McClellan Air Force Base, Operable Unit B/C, CA	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1988	1995
Mid-South Wood Products Superfund Site, AR	Pump and Treat	Groundwater	Semivolatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated; Heavy Metals; Arsenic	1989	1998

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Mystery Bridge at Hwy 20 Superfund Site, Dow/DSI Facility - Volatile Halogenated Organic (VHO) Plume, WY	Pump and Treat; SVE	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1994	1998
Naval Air Station, Brunswick, Eastern Groundwater Plume, ME	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1995	2001
Odessa Chromium I Superfund Site, OU 2, TX	Pump and Treat	Groundwater	Heavy Metals	1993	1998
Odessa Chromium IIS Superfund Site, OU 2, TX	Pump and Treat	Groundwater	Heavy Metals	1993	1998
Offutt AFB, Site LF-12, NE	Pump and Treat	Groundwater	BTEX; Volatiles-Nonhalogenated; TCE; DCE; Volatiles-Halogenated	1997	1998
Old Mill Superfund Site, OH	Pump and Treat	Groundwater	TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1989	1998
Ott/Story/Cordova Superfund Site, North Muskegon, MI	Pump and Treat	Groundwater	PCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; PCBs; Semivolatiles-Halogenated; Pesticides/Herbicides	1996	2001
Paducah Gaseous Diffusion Plant, KY	Pump and Treat (Field Demonstration)	Groundwater	Radioactive Metals	1999	2003
Pinellas Northeast Site, FL	Pump and Treat (Membrane Filtration - PerVap™) (Field Demonstration)	Groundwater	TCE; DCE; Volatiles-Halogenated	1995	1998

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Pope AFB, Site FT-01, NC	Pump and Treat; Free Product Recovery	Groundwater; LNAPLs	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1993	1998
Pope AFB, Site SS-07, Blue Ramp Spill Site, NC	Pump and Treat; Free Product Recovery	Groundwater; LNAPLs	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1993	1998
Rockaway, NJ	Pump and Treat	Drinking Water	MTBE; BTEX; Volatiles-Nonhalogenated; TCE; Volatiles-Halogenated	1980	2001
SCRDI Dixiana Superfund Site, SC	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1992	1998
Shaw AFB, Site OT-16B, SC	Pump and Treat	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	1995	1998
Shaw AFB, Sites SD-29 and ST-30, SC	Pump and Treat; Free Product Recovery	Groundwater; LNAPLs	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated	1995	1998
Sol Lynn/Industrial Transformers Superfund Site, TX	Pump and Treat	Groundwater	TCE; Volatiles-Halogenated	1993	1998
Solid State Circuits Superfund Site, MO	Pump and Treat	Groundwater; DNAPLs	TCE; DCE; Volatiles-Halogenated	1993	1998
Solvent Recovery Services of New England, Inc. Superfund Site, CT	Pump and Treat; Containment - Barrier Walls	Groundwater	Semivolatiles-Nonhalogenated; PCBs; Semivolatiles-Halogenated; Heavy Metals; TCE; DCE; Volatiles-Halogenated	1995	1998

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Sylvester/Gilson Road Superfund Site, NH	Pump and Treat; Containment - Barrier Walls; Containment - Caps; SVE	Groundwater; LNAPLs	Volatiles-Halogenated; Ketones; BTEX; Volatiles-Nonhalogenated; Heavy Metals	1982	1998
Tacony Warehouse, PA	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1998	2000
Twin Cities Army Ammunition Plant, MN	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1987	1995
Union Chemical Company Superfund Site, ME	Pump and Treat; Chemical Oxidation/Reduction (in situ); SVE	Groundwater; Soil	TCE; DCE; Volatiles-Halogenated	1996	2001
United Chrome Superfund Site, OR	Pump and Treat	Groundwater	Heavy Metals	1988	1998
U.S. Aviex Superfund Site, MI	Pump and Treat	Groundwater; DNAPLs	Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1993	1998
U.S. Department of Energy Kansas City Plant, MO	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; Semivolatiles-Halogenated PCBs; Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated; Heavy Metals	1983	1995
U.S. Department of Energy Savannah River Site, A/M Area, SC	Pump and Treat	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	1985	1995

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Western Processing Superfund Site, WA	Pump and Treat; Containment - Barrier Walls	Groundwater; LNAPLs; DNAPLs	TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; PAHs; Semivolatiles-Nonhalogenated; Heavy Metals	1988	1998
***In Situ* Groundwater Bioremediation (36 Projects)**					
Abandoned Manufacturing Facility - Emeryville, CA	Bioremediation (in situ) Enhanced Bioremediation	Groundwater	TCE; Volatiles-Halogenated; Heavy Metals	1997	2000
Altus Air Force Base, Landfill 3 (LF 3), OK	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated	2000	2003
Avco Lycoming Superfund Site, PA	Bioremediation (in situ) Enhanced Bioremediation	Groundwater	TCE; DCE; Volatiles-Halogenated; Heavy Metals	1997	2000
Balfour Road Site, CA; Fourth Plain Service Station Site, WA; Steve's Standard and Golden Belt 66 Site, KS	Bioremediation (in situ) Enhanced Bioremediation	Groundwater	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1995	1998
Brownfield Site, Chattanooga, TN (specific site name not identified)	Bioremediation (in situ) Enhanced Bioremediation	Groundwater	MTBE; BTEX; Volatiles-Nonhalogenated	1999	2001
Contemporary Cleaners, Orlando. FL	Bioremediation (in situ) Enhanced Bioremediation (HRC)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001
Cordray's Grocery, Ravenel, SC	Bioremediation (in situ) Enhanced Bioremediation (ORC)	Groundwater	BTEX; MTBE Volatiles-Nonhalogenated; Semivolatiles-Nonhalogenated	1998	2001

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Dover Air Force Base, Area 6, DE	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	TCE; DCE; Volatiles-Halogenated	1996	2002
Dover Air Force Base, Area 6, DE	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1996	2000
Edwards Air Force Base, CA	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated	1996	2000
French Ltd. Superfund Site, TX	Bioremediation (in situ) Enhanced Bioremediation	Groundwater	BTEX; Volatiles-Halogenated; Volatiles-Nonhalogenated	1992	1998
Gas Station, Cheshire, CT (specific site name not identified)	Bioremediation (in situ) Enhanced Bioremediation	Groundwater	BTEX; MTBE Volatiles-Nonhalogenated	1997	2001
Hanford Site, WA	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	Volatiles-Halogenated	1995	2000
Hayden Island Cleaners, Portland, OR	Bioremediation (in situ) Enhanced Bioremediation (HRC)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001
Idaho National Engineering and Environmental Laboratory, Test Area North, ID	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	1999	2002
ITT Roanoke Site, VA	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	DCE; Volatiles-Halogenated	1998	Not Provided
Lawrence Livermore National Laboratory, CA	Bioremediation (in situ) Enhanced Bioremediation	Groundwater; Soil	MTBE Volatiles-Nonhalogenated	Not Provided	2001

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Libby Groundwater Superfund Site, MT	Bioremediation (in situ) Enhanced Bioremediation; Pump and Treat	Groundwater	Semivolatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated	1991	1998
Moffett Field Superfund Site, CA	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	Volatiles-Halogenated	1986	2000
Multiple (4) Dry Cleaner Sites - *In Situ* Bioremediation, Various Locations	Bioremediation (in situ) Enhanced Bioremediation	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; Volatiles-Nonhalogenated; BTEX; MTBE	Various years - starting 2002	2003
Multiple Dry Cleaner Sites	Bioremediation (in situ) Enhanced Bioremediation (HRC)	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	Not Provided	2001
Naval Weapons Industrial Reserve Plant (NWIRP) , TX	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	TCE, Volatiles-Halogenated	1999	2003
Naval Weapons Station Seal Beach, CA	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater; Soil; LNAPLs	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1997	2000
Offutt Air Force Base, NE	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated	Not provided	2003
Pinellas Northeast Site, FL	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater; DNAPLs	TCE; DCE; Volatiles-Halogenated	1997	1998
Savannah River Site, SC	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater; Sediment	PCE; TCE; Volatiles-Halogenated	1992	2000
Service Station, CA (specific site name not identified)	Bioremediation (in situ) Enhanced Bioremediation (ORC)	Groundwater	BTEX; MTBE; Volatiles-Nonhalogenated	Not Provided	2001

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Service Station, Lake Geneva, WI (specific site name not identified)	Bioremediation (in situ) Enhanced Bioremediation (ORC)	Groundwater	BTEX; MTBE; Volatiles-Nonhalogenated	Not Provided	2001
Site A (actual name confidential), NY	Bioremediation (in situ) Enhanced Bioremediation; Pump and Treat; Air Sparging; SVE	Groundwater	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1995	1998
South Beach Marine, Hilton Head, SC	Bioremediation (in situ) Enhanced Bioremediation	Groundwater	PAHs; Semivolatiles-Nonhalogenated; BTEX; MTBE; Volatiles-Nonhalogenated	1999	2001
Specific site name not identified	Bioremediation (in situ) Enhanced Bioremediation (Bench Scale)	Groundwater; Soil	MTBE; Volatiles-Nonhalogenated	Not Provided	2001
Texas Gulf Coast Site, TX	Bioremediation (in situ) Enhanced Bioremediation	Groundwater	TCE; Volatiles-Halogenated; Heavy Metals	1995	2000
U.S. Department of Energy Savannah River Site, M Area, SC	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater; Sediment	PCE; TCE; Volatiles-Halogenated	1992	1997
U.S. Navy Construction Battalion Center, Port Hueneme, CA	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	MTBE; BTEX; Volatiles-Nonhalogenated	1998	2001
Vandenberg Air Force Base, Lompoc, CA	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater	MTBE; BTEX; Volatiles-Nonhalogenated	1999	2001
Watertown Site, MA	Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater; Soil	PCE; TCE; Volatiles-Halogenated	1996	2000

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Other *In Situ* Groundwater Treatment (72 Projects)					
328 Site, CA	Multi Phase Extraction; Fracturing	Groundwater; Soil	TCE; Volatiles-Halogenated	1996	2000
A.G. Communication Systems, IL	Thermal Treatment (in situ)	Groundwater; Soil	TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1995	2003
Aberdeen Proving Grounds, Edgewood Area J - Field Site, MD	Phytoremediation (Field Demonstration)	Groundwater	TCE; DCE; Volatiles-Halogenated	1996	2002
Amcor Precast, UT	In-Well Air Stripping; SVE	Groundwater; Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated; PAHs; Semivolatiles-Nonhalogenated	1992	1995
Brookhaven National Laboratory, NY	In-Well Air Stripping (Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1999	2002
Butler Cleaners, Jacksonville, FL	Chemical Oxidation/Reduction (in situ) ($KMnO_4$)	Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	Not Provided	2001
Camp Lejeune Marine Corps Base, Bldg 25, Camp Lejeune, NC	Flushing (in situ) (SEAR and PITT)	Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	1999	2001
Cape Canaveral Air Force Station, Launch Complex 34, FL	Chemical Oxidation/Reduction (in situ) (Field Demonstration)	Groundwater; DNAPLs	TCE; Volatiles-Halogenated	1999	2003
Cape Canaveral Air Force Station, Launch Complex 34, FL	Thermal Treatment (in situ) (Field Demonstration)	Groundwater; Soil; DNAPLs	TCE; Volatiles-Halogenated	1999	2003

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Carswell Air Force Base, TX	Phytoremediation (Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated	1996	2002
Clear Creek/Central City Superfund site, CO	Phytoremediation (Field Demonstration)	Groundwater	Heavy Metals	1994	2003
Confidential Manufacturing Facility, IL	Thermal Treatment (in situ)	Groundwater; Soil; DNAPLs	TCE; DCE; Volatiles-Halogenated	1998	2000
Defense Supply Center, Acid Neutralization Pit, VA	Multi Phase Extraction (Field Demonstration)	Groundwater; Soil	PCE; TCE; DCE; Volatiles-Halogenated	1997	2000
Eaddy Brothers, Hemingway, SC	Air Sparging; SVE	Groundwater; Soil	BTEX; MTBE Volatiles-Nonhalogenated; Semivolatiles-Nonhalogenated	1999	2001
Edward Sears Site, NJ	Phytoremediation (Field Demonstration)	Groundwater	PCE; TCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1996	2002
Eight Service Stations, MD (specific sites not identified)	Multi Phase Extraction	Groundwater; Soil; LNAPLs	BTEX; MTBE Volatiles-Nonhalogenated	1990	2001
Fernald Environmental Management Project, OH	Flushing (in situ) (Field Demonstration)	Groundwater	Heavy Metals	1998	2001
Former Intersil, Inc. Site, CA	Permeable Reactive Barrier; Pump and Treat	Groundwater	TCE; DCE; Volatiles-Halogenated	1995	1998
Former Nu Look One Hour Cleaners, Coral Springs, FL	In-Well Air Stripping (NoVOCs™)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Former Sages Dry Cleaners, Jacksonville, FL	Flushing (in situ) (Ethanol Co-solvent)	Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001
Fort Devens, AOCs 43G and 43J, MA	Monitored Natural Attenuation	Groundwater; Soil; LNAPLs	BTEX; Volatiles-Nonhalogenated	1997	2000
Fort Richardson, AK	Thermal Treatment (in situ) (Field Demonstration)	Groundwater; Soil; DNAPLs; Off-gases	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1999	2003
Four Service Stations (specific site names not identified)	Air Sparging	Groundwater	BTEX; MTBE Volatiles-Nonhalogenated	1993	2001
Fry Canyon, UT	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Radioactive Metals; Heavy Metals	1997	2000
Gold Coast Superfund Site, FL	Air Sparging; Pump and Treat	Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1994	1998
Hanford Site, 100-H and 100-D Areas, WA	Chemical Oxidation/Reduction (in situ) (Field Demonstration)	Groundwater	Heavy Metals	1995	2000
ICN Pharmaceuticals, OR	Thermal Treatment (in situ); SVE	Groundwater; Soil; DNAPLs	TCE; DCE; Volatiles-Halogenated	2000	2003
Johannsen Cleaners, Lebanon, OR	Multi Phase Extraction	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001
Keesler Air Force Base Service Station, AOC-A (ST-06), MS	Monitored Natural Attenuation	Groundwater; Soil	BTEX; Volatiles-Nonhalogenated; Heavy Metals	1997	2000

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Kelly Air Force Base, Former Building 2093 Gas Station, TX	Monitored Natural Attenuation	Groundwater; Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1997	2000
Lawrence Livermore National Laboratory Gasoline Spill Site, CA	Thermal Treatment (in situ) (Field Demonstration)	Groundwater; Soil	BTEX; Volatiles-Nonhalogenated	1992	1995
Louisiana Army Ammunition Plant, LA	Monitored Natural Attenuation	Groundwater	Explosives/Propellants	Not Provided	2001
Marshall Space Flight Center, AL	Chemical Oxidation/Reduction (in situ); Fracturing; Permeable Reactive Barrier (Field Demonstration)	Groundwater	Tetrachloroethene (TCE); Volatiles-Halogenated	2000	2003
Massachusetts Military Reservation, CS-10 Plume, MA	In-Well Air Stripping (UVB and NoVOCs) (Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1996	2002
McClellan Air Force Base (AFB), OU A, CA	Air Sparging; Bioremediation (in situ) Enhanced Bioremediation (Field Demonstration)	Groundwater; Soil	TCE; DCE; Volatiles-Halogenated	1999	2003
Miamisburg, OH	Air Sparging; SVE	Groundwater; Soil	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1997	2001
Milan Army Ammunition Plant, TN	Phytoremediation (Field Demonstration)	Groundwater	Explosives/Propellants	1996	2000
Moffett Federal Airfield, CA	Permeable Reactive Barrier (Field Demonstration)	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	1996	1998
Moffett Field Superfund Site, CA	Permeable Reactive Barrier (Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1996	2000

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Monticello Mill Tailings Site, Monticello, UT	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Metals	1999	2001
Multiple (2) Dry Cleaner Sites, Various Locations	Chemical Oxidation/Reduction (in situ)	Groundwater; Dense Non-aqueous Phase Liquids (DNAPLs)	PCE; TCE; Volatiles-Halogenated	Various years - starting 1998	2003
Multiple (10) Sites - Air Sparging, Various Locations	Air Sparging	Groundwater; Soil	TCE; PCE; DCE; Volatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated; BTEX; Volatiles-Nonhalogenated; MTBE; Petroleum Hydrocarbons	Various years	2003
Multiple Air Force Sites	Multi Phase Extraction (Field Demonstration)	Groundwater; LNAPLs	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	Not Provided	2001
Multiple Air Force Sites	Monitored Natural Attenuation (Field Demonstration)	Groundwater	TCE; DCE; Volatiles-Halogenated	1993	1999
Multiple Air Force Sites	Monitored Natural Attenuation (Field Demonstration)	Groundwater	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1993	1999
Multiple DoD Sites, Various Locations	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Volatiles-Halogenated	Various years	2003
Multiple Dry Cleaner Sites	Air Sparging; SVE	Groundwater; Soil; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001, 2002
Multiple Dry Cleaner Sites	Chemical Oxidation/Reduction (in situ) (Field Demonstration)	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	1999	2001, 2002

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Multiple Dry Cleaner Sites	Flushing (in situ); Thermal Treatment (in situ); In-Well Air Stripping (Field Demonstration)	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	Not Provided	2001
Multiple Dry Cleaner Sites	Multi Phase Extraction; Pump and Treat	Groundwater; Soil; DNAPLs	PCE; TCE; Volatiles-Halogenated	Not Provided	2001, 2002
Multiple Sites	Permeable Reactive Barrier (Full scale and Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1991	2002
Multiple Sites	Permeable Reactive Barrier (Full scale and Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated; Heavy Metals; Radioactive Metals; Arsenic	1997	2002
Multiple Sites	Permeable Reactive Barrier (Full scale and Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Heavy Metals; Radioactive Metals; Arsenic	1995	2002
Multiple Sites	Permeable Reactive Barrier (Full scale and Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Heavy Metals; Radioactive Metals; Pesticides/Herbicides	1995	2002

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Multiple Sites	Permeable Reactive Barrier (Full scale and Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; Heavy Metals; Radioactive Metals	1995	2002
Naval Air Station, North Island, CA	In-Well Air Stripping (NoVOCs) (Field Demonstration)	Groundwater	TCE; DCE; Volatiles-Halogenated	1998	2000
Naval Air Station, Pensacola, FL	Chemical Oxidation/Reduction (in situ)	Groundwater	TCE; DCE; Volatiles-Halogenated	1998	2001
Naval Air Station Pensacola, OU 10, FL	Chemical Oxidation/Reduction (in situ) (Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated	1998	2000
Naval Submarine Base, Kings Bay, GA	Chemical Oxidation/Reduction (in situ)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1998	2000
Naval Submarine Base, Kings Bay, GA	Chemical Oxidation/Reduction (in situ); Monitored Natural Attenuation	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1999	2001
Oak Ridge National Laboratory, TN	Permeable Reactive Barrier - Funnel and Gate Configuration and Trench (Field Demonstration)	Groundwater	Radioactive Metals	1997	2002
Pinellas Northeast Site, FL	Thermal Treatment (in situ) - Dual Auger Rotary Steam Stripping (Field Demonstration)	Groundwater; Soil; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1996	1998
Portsmouth Gaseous Diffusion Plant, X-701B Facility, OH	Chemical Oxidation/Reduction (in situ) (Field Demonstration)	Groundwater; DNAPLs	TCE; Volatiles-Halogenated	1988	2000

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
RMI Titanium Plant, Ashtabula Environmental Management Project, OH	Flushing (in situ) (WIDE) (Field Demonstration)	Groundwater; Soil	TCE; Volatiles-Halogenated; Radioactive Metals	1999	2001
Scotchman #94, Florence, SC	Multi Phase Extraction; Air Sparging; SVE	Groundwater; Soil	Polycyclic Aromatic Hydrocarbon (PAHs); Semivolatiles-Nonhalogenated; BTEX; MTBE; Volatiles-Nonhalogenated	1998	2001
Site 88, Building 25, Marine Corps Base Camp Lejeune, NC	Flushing (in situ) (SEAR) (Field Demonstration)	Groundwater; DNAPLs; LNAPLs	Petroleum Hydrocarbons; Volatiles-Nonhalogenated; PCE; Volatiles-Halogenated	1999	2001
South Prudence Bay Island Park, T-Dock Site, Portsmouth, RI	Air Sparging; Bioremediation (in situ) Enhanced Bioremediation	Groundwater	BTEX; Volatiles-Nonhalogenated	1998	2001
Sparks Solvents/Fuel Site, Sparks, NV	Multi Phase Extraction	Groundwater; LNAPLs	BTEX; MTBE; Volatiles-Nonhalogenated; PCE; TCE; Volatiles-Halogenated	1995	2001
Tinkham's Garage Superfund Site, NH	Multi Phase Extraction	Groundwater; Soil	PCE; TCE; Volatiles-Halogenated	1994	2000
U.S. Coast Guard Support Center, NC	Permeable Reactive Barrier	Groundwater; DNAPLs	TCE; Volatiles-Halogenated; Heavy Metals	1996	1998
U.S. Department of Energy Savannah River Site, A/M Area, SC	In-Well Air Stripping; Pump and Treat (Field Demonstration)	Groundwater; Soil; DNAPLs	PCE; TCE; Volatiles-Halogenated	1990	1995
Visalia Superfund Site, CA	Thermal Treatment (in situ) (Field Demonstration)	Groundwater	Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1997	2000

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Debris/Solid Media Treatment (28 Projects)					
Alabama Army Ammunition Plant, AL	Thermal Desorption (ex situ) (Field Demonstration)	Debris/Slag/ Solid	Explosives/Propellants	1995	1998
Argonne National Laboratory - East, IL	Physical Separation (Concrete Demolition) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	2000
Argonne National Laboratory - East, IL	Physical Separation (Scabbling) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	Not Provided	2000
Argonne National Laboratory, IL	Solidification/Stabilization (Phosphate Bonded Ceramics) (Field Demonstration)	Debris/Slag/ Solid; Groundwater	Heavy Metals	Not Provided	2000
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	Physical Separation (Centrifugal Shot Blast) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	1998
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	Physical Separation (Rotary Peening with Captive Shot) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	1998
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	Physical Separation (Roto Peen Scaler with VAC-PAC® System) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1996	1998
Clemson University, SC	Solidification/Stabilization (Sintering) (Bench Scale)	Debris/Slag/ Solid	Heavy Metals	1995	2000
Envirocare of Utah, UT	Solidification/Stabilization (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1996	1998
Fernald Site, OH	Physical Separation (Soft Media Blasting) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1996	2000
Hanford Site, C Reactor, WA	Solidification/Stabilization (Polymer Coating) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	1998
Hanford Site, WA	Physical Separation (Concrete Grinder) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	2000
Hanford Site, WA	Physical Separation (Concrete Shaver) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	2000

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Hanford Site, WA	Physical Separation (Concrete Spaller) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1998	2000
Hanford Site, WA	Physical Separation; Solvent Extraction (Ultrasonic Baths) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1998	1998
Hanford Site, WA	Solidification/Stabilization (Polyester Resins) (Field Demonstration)	Debris/Slag/ Solid; Groundwater	Radioactive Metals; Heavy Metals; Arsenic	Not Provided	2000
Idaho National Engineering and Environmental Laboratory, ID	Physical Separation (Wall Scabbler) (Field Demonstration)	Debris/Slag/ Solid	Heavy Metals	2000	2001
Idaho National Engineering and Environmental Laboratory, ID	Solidification/Stabilization (DeHg^{SM} Process) (Field Demonstration)	Debris/Slag/ Solid	Heavy Metals	1998	2000
Idaho National Engineering and Environmental Laboratory, ID	Solidification/Stabilization (Innovative Grouting and Retrieval) (Full scale and Field Demonstration)	Debris/Slag/ Solid; Soil	Radioactive Metals	1994	2000
Idaho National Engineering and Environmental Laboratory, ID	Vitrification (ex situ) (Graphite Furnace) (Field Demonstration)	Debris/Slag/ Solid; Organic Liquids; Soil	Heavy Metals; Radioactive Metals	1997	2000
Idaho National Engineering and Environmental Laboratory, Pit 2, ID	Solidification/Stabilization (Polysiloxane) (Field Demonstration)	Debris/Slag/ Solid; Groundwater	Heavy Metals	1997	2000
Lawrence Livermore National Laboratory, CA	Chemical Oxidation/Reduction (ex situ) (Field Demonstration)	Debris/Slag/ Solid; Groundwater	PCE; TCE; Volatiles-Halogenated PCBs; Semivolatiles-Halogenated; Explosives/Propellants	Not Provided	2000
Los Alamos National Laboratory, NM	Solidification/Stabilization (ADA Process) (Field Demonstration)	Debris/Slag/ Solid	Heavy Metals	1998	2000
Los Alamos National Laboratory, Technical Area 33, NM	Solidification/Stabilization (Field Demonstration)	Sludge	Heavy Metals; DCE; Volatiles-Halogenated; Radioactive Metals	1997	2000

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Pacific Northwest National Laboratory, WA	Solidification/Stabilization (Sol Gel Process) (Bench Scale)	Debris/Slag/ Solid; Groundwater	Heavy Metals	Not Provided	2000
Portsmouth Gaseous Diffusion Plant, OH	Solidification/Stabilization (ATG Process) (Field Demonstration)	Organic Liquids	Heavy Metals; Radioactive Metals	1998	2000
Savannah River Site, SC	Acid Leaching (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1996	2000
STAR Center, ID	Vitrification (ex situ) (Plasma Process) (Field Demonstration)	Debris/Slag/ Solid; Soil; Sludge	Heavy Metals; Radioactive Metals	1993	2000
Containment (7 Projects)					
Dover Air Force Base, Groundwater Remediation Field Laboratory National Test Site, Dover DE	Containment - Barrier Walls (Field Demonstration)	Groundwater	-	1996	2001
Lawrence Livermore National Laboratory (LLNL) Site 300 - Pit 6 Landfill OU, CA	Containment - Caps	Debris/Slag/ Solid	TCE; Volatiles-Halogenated; Radioactive Metals	1997	1998
Marine Corps Base Hawaii, HI	Containment - Caps (Field Demonstration)	Soil	-	1994	1998
Naval Shipyard, CA	Containment - Caps (Field Demonstration)	Soil	BTEX; Volatiles-Nonhalogenated	1997	1998
Oak Ridge National Laboratory, TN	Containment - Barrier Walls (Field Demonstration)	Soil; Sediment; Groundwater	Radioactive Metals	1996	2000

EXHIBIT A-1. SUMMARY OF 342 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Sandia National Laboratory, Albuquerque, NM	Containment - Caps (Field Demonstration)	Soil	-	1995	2001
U.S. Department of Energy, SEG Facilities, TN	Containment - Barrier Walls (Field Demonstration)	Soil	-	1994	1997

* Full scale unless otherwise noted
† Technology focused on in case study listed first, followed by other technologies identified in the case study

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
MTBE = Methyl tert butyl ether

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