Abstracts of Remediation Case Studies

Volume 6

Federal Remediation Technologies Roundtable <www.frtr.gov>

Prepared by the

Member Agencies of the Federal Remediation Technologies Roundtable

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Federal Remediation Technologies Roundtable

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

Department of Energy
Department of Interior
National Aeronautics and Space Administration

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FOREWORD

This report is a collection of abstracts summarizing 39 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 313 remediation technology case studies (the 39 new case studies and 274 previously-published case studies). Appendix A to this report identifies the specific sites, technologies, contaminants, media, and year published for the 313 case studies.

Abstracts, Volume 6, 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.

2002 Series

CD-ROM: FRTR Cost and Performance Case Studies and Related Information, 3rd Edition; EPA-542-C-02-004; July 2002

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

Accessing Case Studies

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

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

In addition, a limited number of copies of the CD-ROM and Abstracts - Volume 6 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. Previously, the Roundtable published 13 volumes and a CD-ROM of case study reports. At this time, the Roundtable is publishing a CD-ROM containing 39 new case study reports (313 reports total), primarily focused on contaminated soil and groundwater cleanup. The CD-ROM also includes 274 previously published reports.

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

The case studies and abstracts present available cost and performance information for full-scale remediation efforts and several large-scale demonstration projects. They are meant to serve as primary reference sources, and contain information on site background, contaminants and media treated, technology, cost and performance, and points of contact for the technology application. The case studies contain varying levels of detail, reflecting the differences in the availability of data and information about the application.

The case study abstracts in this volume describe a wide variety of *ex situ* and *in situ* soil treatment technologies for both soil and groundwater. Contaminants treated included chlorinated solvents; petroleum hydrocarbons and benzene, toluene, ethylbenzene, and xylenes; polycyclic aromatic hydrocarbons; pesticides and herbicides; metals; and radioactive materials.

Table 1 provides summary information about the technology used, contaminants and media treated, and project duration for the 39 technology applications in this volume. This table also provides highlights about each application. Table 2 summarizes cost data, including information about quantity of media treated and quantity of contaminant removed. In addition, Table 2 shows a calculated unit cost for some projects, and identifies key factors potentially affecting technology cost. (The column showing the calculated unit costs for treatment provides a dollar value per quantity of media treated and contaminant removed, as appropriate.) The cost data presented in the table were taken directly from the case studies and have not been adjusted for inflation to a common year basis. The costs should be assumed to be dollars for the time period that the project was in progress (shown on Table 1 as project duration).

By including a recommended reporting format, the Roundtable is working to standardize the reporting of costs to make data comparable across projects. In addition, the Roundtable is working to capture information in case study reports that identify and describe the primary factors that affect cost and performance of a given technology. Factors that may affect project costs include economies of scale, concentration levels in contaminated media, required cleanup levels, completion schedules, and matrix characteristics and operating conditions for the technology.

Appendix A to this report provides a summary of key information about all 313 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	Metals	Radionuclides			
***In Situ* Soil Treatment**								
Soil Vapor Extraction (SVE)								
Multiple (7) Dry Cleaner Sites (Soil Vapor Extraction)	●					Soil	Various dates from 1998 - December 2000	Use of SVE to remediate soil contaminated with chlorinated solvents at drycleaning sites
Stamina Mills Superfund Site, North Smithfield, RI (Soil Vapor Extraction)	●					Off-gas	August - October 1999	Field demonstration of a photocatalytic reactor to treat off-gas from soil vapor extraction (SVE) and multi-phase extraction (MPE)
Other *In Situ* Soil Treatment								
Castle Airport, Port Merced, CA (Bioventing)		●				Soil	March 1998 - October 1998	Field demonstration of natural pressure-driven passive bioventing of petroleum-contaminated soil
Magic Marker, Trenton, NJ and Small Arms Firing Range (SAFR) 24, Fort Dix, NJ (Phytoremediation)				●		Soil (Magic Marker - 77ft x 50 ft x 6 in deep; Fort Dix - 1.25 ac by 12 in deep)	Magic Marker - May 1997 to November 1998; Fort Dix - April 2000 to October 2000	Magic Marker - Field demonstration of phytoremediation treatment of lead in surface soil Fort Dix - Field demonstration of phytoremediation treatment of lead concentrations in soil following soil washing
Naval Air Weapons Station Point Mugu Site 5, CA (Electrokinetics)				●		Soil and Sediment (0.5 ac)	March 1998 - October 1998	Field demonstration of electrokinetic treatment of chromium and cadmium in soil

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	Metals	Radionuclides			
***Ex Situ* Soil Treatment**								
Bioremediation								
Naval Construction Battalion Center Hydrocarbon National Test Site, Port Hueneme, CA (Bioremediation)		●				Soil (10 yd^3)	October 1996 - January 1997	Field demonstration of an *ex situ* bioremediation technology to treat small quantities of petroleum-contaminated soils
Peerless Cleaners, WI; Stannard Launders and Dry Cleaners, WI (Bioremediation)	●					Soil (Peerless - 18 tons; Stannard - 594 tons)	Not Specified	Use of biopiles to treat contaminated soil from drycleaning operations
Thermal Desorption								
Cape Fear Superfund Site, Fayetteville, NC (Thermal Desorption)		●				Soil (170,300 tons)	July 1998 - April 1999	Thermal desorption of a large volume of soil contaminated with wood preserving chemicals containing PAHs, and benzene
Lipari Landfill, Operable Unit 3, Pitman, NJ (Thermal Desorption)	●	●				Soil (80,000 tons)	September 1994 - September 1995	Thermal desorption of soil contaminated with VOCs, and SVOCs
Reilly Industries Superfund Site, Operable Unit 3 Indianapolis, IN (Thermal Desorption)		●				Soil (3,700 tons)	November 1996 - January 1997	Thermal desorption of soil containing PAHs, benzene, toluene, and pyridine from coal tar refining and wood preserving

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*: Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Metals	Radionuclides	Media (Quantity Treated)	Project Duration	Highlights
***In Situ* Groundwater Treatment**								
Bioremediation								
Dover AFB, Area 6, Dover, DE (Bioremediation)	●					Groundwater (2.7 million gallons)	May 1996 - March 1998	Field demonstration of bioremediation to treat DNAPL in groundwater
Idaho National Engineering and Environmental Laboratory, Test Area North, Idaho Falls, ID (Bioremediation)	●					Groundwater	1999 - 2000	Field demonstration of *in situ* bioremediation to treat groundwater contaminated with VOCs
ITT Roanoke Site, Roanoke, VA (Bioremediation)	●					Groundwater	March 1998 - July 1999	Field demonstration of an enhanced *in situ* bioremediation process for chlorinated organics in groundwater in fractured bedrock
Multiple (6) Dry Cleaner Sites (Bioremediation)	●					Groundwater (Surface area - 200 to 18,000 ft^2)	Various dates ranging from 154 days to 20 months	Full-scale remediation and field demonstrations using *in situ* bioremediation to treat chlorinated solvents in groundwater at drycleaner facilities
Flushing								
Marine Corps Base Camp Lejeune, Site 88, Building 25, NC (Surfactant Flushing)	●	●				Groundwater (20 ft x 30 ft x 20 ft)	April - August 1999	Field demonstration of Surfactant-Enhanced Aquifer Flushing (SEAR) surfactant flushing technology for treating PCE and DNAPL in groundwater
Multiple (4) Dry Cleaner Sites (Flushing; *In Situ* Thermal Desorption; In-Well Air Stripping)	●					Groundwater (6,000 to 150,000 ft^3)	Not Specified	Field demonstrations of *in situ* technologies for the remediation of chlorinated solvents in soil and groundwater at drycleaning facilities
RMI Titanium Plant, Ashtabula Environmental Management Project, OH (Flushing)	●				●	Groundwater and Soil (70 ft by 70 ft by 15 ft deep)	January - August 1999	Field demonstration of hybrid soil and groundwater flushing/SVE treatment of TCE and radionuclides in clay soil

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	Metals	Radionuclides			
In-Well Air Stripping								
Brookhaven National Laboratory, Upton, NY (In-Well Air Stripping)	●					Groundwater (278 million gallons through March 2001)	September 29, 1999 - Ongoing (data available through March 2001)	Field demonstration of UVB recirculating well technology to treat groundwater contaminated with VOCs
Massachusetts Military Reservation, CS-10 Plume, Cape Cod, MA (Recirculating Wells)	●					Groundwater (UVB Pilot - 23 million gallons; NoVOCs Pilot Not Provided)	December 21, 1996 - May 4, 1999	Field demonstration of UVB and NoVOCs recirculating well technologies to treat groundwater contaminated with VOCs
Naval Air Station, North Island, San Diego, CA (In-Well Air Stripping)	●					Groundwater	February 1998 - January1999	Field demonstration of NoVOCs in-well air stripping to treat groundwater contaminated with high levels of VOCs
Permeable Reactive Barrier								
Multiple (6) Sites (PRB-Continuous Reactive Wall)	●					Groundwater	Installation dates from 1991 -1998	Full-scale and field demonstrations using PRBs with a continuous wall configuration to treat groundwater contaminated primarily with chlorinated solvents
Multiple (5) Sites (PRB-Continuous Reactive Wall)				●		Groundwater	Installation dates from 1995 - 1999	Full-scale use of PRBs with a continuous wall configuration to treat groundwater contaminated primarily with metals
Multiple (14) Sites (PRB-Funnel and Gate Configuration)	●	●		●	●	Groundwater	Installation dates from 1995 - 2000	Full-scale and field demonstrations using PRBs with a funnel and gate configuration to treat groundwater contaminated with various compounds

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	Metals	Radionuclides			
Multiple (16) Sites (PRB-Injection and Other Emerging Technologies)	●	●	●	●	●	Groundwater	Installation dates from 1995 - 2002	Full-scale and field demonstrations of PRBs using injection or other emerging technologies as an installation method to treat contaminated groundwater
Multiple (8) Sites (PRB-Iron with a Bulking Agent as a Reactive Media)	●			●	●	Groundwater	Installation dates from 1995 - 2000	Full-scale and field demonstrations using PRBs that employed a reactive media consisting of iron with a bulking agent to treat groundwater contaminated with chlorinated solvents, metals, and radionuclides
Oak Ridge National Laboratory, Oak Ridge, TN (Permeable Reactive Barrier)					●	Groundwater (Funnel and Gate PRB - 133,000 gal; Trench PRB - 200,000 to 400,000 gal)	Installed August 1997 (data available through August 1999)	Two field demonstrations of PRB technology to treat groundwater contaminated with uranium
Phytoremediation								
Aberdeen Proving Grounds, Edgewood Area J-Field Site, Edgewood, MD (Phytoremediation)	●					Groundwater	Spring 1996 - Ongoing (data available through 1998)	Long-term field demonstration of phytoremediation to treat chlorinated solvents in groundwater
Carswell Air Force Base, Fort Worth, TX (Phytoremediation)	●					Groundwater	Spring 1996 - Ongoing (data available through 2001)	Long-term field demonstration of phytoremediation to treat chlorinated solvents in groundwater
Edward Sears Site, New Gretna, NJ (Phytoremediation)	●					Groundwater	December 1996 - Ongoing (data available through 1999)	Long-term field demonstration of phytoremediation to treat chlorinated solvents in groundwater

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*					Media (Quantity Treated)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Metals	Radionuclides			
Other *In Situ* Groundwater Treatment								
Multiple (4) Dry Cleaner Sites (Air Sparging and Soil Vapor Extraction)	●					Groundwater (plume surface area 24,000 - 96, 000 ft^2)	Various durations from 1 to 5 years	Use of SVE and air sparging to treat chlorinated solvents in soil and groundwater at drycleaner facilities
Multiple (6) Dry Cleaner Sites (Chemical Oxidation)	●					Groundwater (400 to 7,900 ft^2 x 30 - 45 ft in depth) and Soil	Various dates from July 1999 - Ongoing	Field demonstration of *in situ* oxidation technologies for remediation of chlorinated solvents in soil and groundwater at drycleaner facilities
Multiple (5) Dry Cleaner Sites (Multi-Phase Extraction; Pump and Treat)	●					Groundwater (6,000 to 150,000 ft^3)	Various durations from 3 months to 3 years	Use of multi-phase extraction or pump and treat to treat soil and groundwater contaminated with chlorinated solvents from drycleaning operations
***Ex Situ* Groundwater Treatment**								
Commencement Bay South Tacoma Channel Superfund Site, Tacoma, WA (Pump and Treat)	●					Groundwater (450 million gallons through May 2000)	November, 1998 - Ongoing (data available through June 2000)	Use pump and treat and SVE to treat groundwater and soil contaminated with chlorinated VOCs
Union Chemical Company Superfund Site, South Hope, ME (Pump and Treat)	●					Groundwater (8.4 million gallons through December 1999) and Soil (48,000 yd^3)	January 1996 - Ongoing (data available through October 2000)	Use of pump and treat, SVE, and *in situ* chemical oxidation to treat groundwater and soil contaminated with chlorinated and non-chlorinated VOCs

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*: Chlorinated Solvents	BTEX and/or TPH	Pesticides/Herbicides	Metals	Radionuclides	Media (Quantity Treated)	Project Duration	Highlights
***Ex Situ* Debris/Solid Media Treatment**								
Hanford Site, C Reactor, Richland, WA (Surface Treatment)					●	Debris (Initial Test -metal coupons; Demonstration Test - 9 nozzle assemblies)	August 1997 - March 1998	Field demonstration of surface coating to stabilize contaminated surfaces to minimize radioactive airborne contamination during decontamination and decommissioning
Hanford Site, Richland, WA (Surface Treatment)					●	Debris (78 lead bricks, each measuring 5 cm x 10 cm x 20 cm)	May 1998	Field demonstration of a process that uses ultrasonics and chemical baths to remove radioactive contaminants from surfaces
Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID (Surface Treatment)				●		Debris (60 ft^2)	March 2000	Field demonstration of robotic abrasive blasting to remove lead-based paint from concrete and steel walls and floors
Containment								
Marine Corps Base Hawaii, Kaneohe Bay, HI (Alternative Landfill Cover)						Soil and Solid Waste	1994 - Ongoing (data available for first 16 months of operation)	Field demonstration of evapotranspiration landfill caps as alternatives to conventional RCRA covers
Naval Shipyard Long Beach, CA (Alternative Soil Pile Cover)						Soil (11,000 yd^3)	September 1997 - July 1998	Field demonstration of a polymer coating for a soil pile to contain petroleum vapors and protect against erosion

* 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 (7) Dry Cleaner Sites (Soil Vapor Extraction)	DI - $30,000 - $160,000; AO - $26,000 - $67,000	Not Provided	2 - 7 lbs	Not Provided	Not Provided
Stamina Mills Superfund Site, North Smithfield, RI (Soil Vapor Extraction)	Not Provided	Not Provided	Not Provided	Not Provided	Not Provided
Other *In Situ* Soil Treatment					
Castle Airport, Port Merced, CA (Bioventing)	Not Provided	Not Provided	Not Provided	$1.93/yd^3	Not Provided
Magic Marker, Trenton, NJ and Small Arms Firing Range (SAFR) 24, Fort Dix, NJ (Phytoremediation)	Not Provided	Magic Marker - 77 ft x 50 ft x 6 in deep; Fort Dix - 1.25 acres x 12 in deep	Not Provided	P - $23.87/yd^3 (1-crop *in situ* treatment) - $127.40/yd^3 (3-crop *ex situ* treatment)	Biomass disposal costs vary
Naval Air Weapons Station Point Mugu Site 5, CA (Electrokinetics)	P - $1,193,050 for treatment of 1,000 yd^3; C - $890,988; AO - $302,062	0.5 ac	Not Provided	P - $1,193/yd^3	Not Provided
***Ex Situ* Soil Treatment**					
Bioremediation					
Naval Construction Battalion Center Hydrocarbon National Test Site, Port Hueneme, CA (Bioremediation)	Not Provided	10 yd^3	Not Provided	P - $40.8/yd^3 (One 40-yd^3 biocell); $36.75/yd^3 (Two 40-yd^3 biocells); $36.75/yd^3 (Three 40-yd^3 biocells) (Unit costs amortized over 5 years)	Not Provided
Peerless Cleaners, WI; Stannard Launders and Dry Cleaners, WI (Bioremediation)	DI - Peerless Cleaners- $14,000; Stannard Launders and Dry Cleaners - $39,000	Peerless - 18 tons; Stannard - 594 tons	Not Provided	Not Provided	Not Provided

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

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs
Thermal Desorption					
Cape Fear Superfund Site, Fayetteville, NC (Thermal Desorption)	Total - $9,888,575; C - $1,800,529; AO - $8,088,046	170,300 tons	Not Provided	$58/ton	Not Provided
Lipari Landfill, Operable Unit 3, Pitman, NJ (Thermal Desorption)	Total - $6,082,029; C - $430,000; AO - $5,019,292	80,000 tons	Not Provided	$68/ton	Not Provided
Reilly Industries Superfund Site, Operable Unit 3 Indianapolis, IN (Thermal Desorption)	Total - $1,087,732; C - $270,000; AO - $659,130	3,700 tons	Not Provided	$251/ton	Not Provided
***In Situ* Groundwater Treatment**					
Bioremediation					
Dover AFB, Area 6, Dover, DE (Bioremediation)	DI - $596,000 (estimated net present value)	2.7 million gallons	3.6 lbs	Not Provided	Not Provided
Idaho National Engineering and Environmental Laboratory, Test Area North, Idaho Falls, ID (Bioremediation)	Total - $35,410,000 (estimated net present value for 15 years); C - $3,750,000; AO - $31,508,000; D&D - $152,000	Not Provided	Not Provided	Not Provided	Not Provided
ITT Roanoke Site, Roanoke, VA (Bioremediation)	Not Provided	Not Provided	Not Provided	Not Provided	Not Provided
Multiple (6) Dry Cleaner Sites (Bioremediation)	Total - $79,000 - $300,000	200 - 18,000 ft^2	Not Provided	Not Provided	Costs do not include site assessment
Flushing					
Marine Corps Base Camp Lejeune, Site 88, Building 25, NC (Surfactant Flushing)	D - $3.1 million; P - 1.5 million (for 2,500 ft^2); $6.8 million (for 0.5 ac); $12.8 million (1 acre)	20ft x 30 ft x 20 ft	76 gallons	Not Provided	Not Provided

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

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs
Multiple (4) Dry Cleaner Sites (Flushing; Thermal Desorption; In-Well Air Stripping)	Cedarburg Drycleaners: DI - $48,000 (soil treatment) and $44,000 (groundwater treatment); Former Nu Look One Hour Cleaners: Total - $193, 000; Former Sages Drycleaners: DI - $440,000	Groundwater - 6,000 - 150,000 ft^3; Soil: Cedarburg Drycleaners - 100 ft^3	Not Provided	Not Provided	Not Provided
RMI Titanium Plant, Ashtabula Environmental Management Project, OH (Flushing)	C- $386,000; AO - $200,000 (estimate); Projected for 1.25-ac plume: C - $1.3 million; AO - 0.2 million over 5 years	Soil - 70 ft x 70ft x 15 ft	Not Provided	Not Provided	Not Provided
In-Well Air Stripping					
Brookhaven National Laboratory, Upton, NY (In-Well Air Stripping)	Not Provided	278 million gallons (through March 2001)	300 lbs	Not Provided	Estimated cost savings for UVB system compared to Pump and Treat system = $161,000
Massachusetts Military Reservation, CS-10 Plume, Cape Cod, MA (Recirculating Wells)	D - $3,000,000	23 million gallons (UVB Pilot); NoVOCs Pilot Not Provided	Not Provided	Not Provided	Not Provided
Naval Air Station, North Island, San Diego, CA (In-Well Air Stripping)	C (projected) - $190,000; AO (projected) - $160,000 for first year, $150,000 thereafter	Not Provided	92.5 lbs	Not Provided	Not Provided

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

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs
Permeable Reactive Barrier					
Multiple (6) Sites (PRB-Continuous Reactive Wall)	Design cost/site - $50,000 - $200,000; Implementation cost/site - $30,000 - $1.3 million	Not Provided	Not Provided	Not Provided	Not Provided
Multiple (5) Sites (PRB-Continuous Reactive Wall)	Installation cost/site - $30,000 - $500,000	Not Provided	Not Provided	Not Provided	Not Provided
Multiple (13) Sites (PRB-Funnel and Gate Configuration)	Design cost/site - $30,000 - $240,000; Installation cost/site - $67,200 - $1 million	Not Provided	Not Provided	Not Provided	Not Provided
Multiple (16) Sites (PRB-Injection and other emerging technologies)	Design cost/site - $30,000 - $292,000; Installation cost/site - $130,000 - $5 million	Not Provided	Not Provided	Not Provided	Not Provided
Multiple (8) Sites (PRB-Iron with a Bulking Agent as a Reactive Media)	Installation cost/site - $278,000 - $2.4 million	Not Provided	Not Provided	Not Provided	Not Provided
Oak Ridge National Laboratory, Oak Ridge, TN (Permeable Reactive Barrier)	Funnel and Gate PRB Installation Cost - $943,000	Funnel and Gate PRB - 133,000 gallons; Trench PRB - 200,000 - 400,000 gallons	Not Provided	Not Provided	Not Provided
Phytoremediation					
Aberdeen Proving Grounds, Edgewood Area J-Field Site, Edgewood, MD (Phytoremediation)	C - $80/tree; Initial site preparation - $5,000; UXO clearance during planting - $80,000; AO - $30,000	Not Provided	Not Provided	Not Provided	Not Provided

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

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs
Carswell Air Force Base, Fort Worth, TX (Phytoremediation)	Site preparation - $22,000; Site Work - $171,200; AO - $2,000 + costs for research level monitoring	Not Provided	Not Provided	Not Provided	Not Provided
Edward Sears Site, New Gretna, NJ (Phytoremediation)	Installation - $105,000; Site preparation - $24,000; Planting - $65,700; Maintenance - $15,300	Not Provided	Not Provided	Not Provided	Not Provided
Other *In Situ* Groundwater Treatment					
Multiple (4) Dry Cleaner Sites (Air Sparging and Soil Vapor Extraction)	DI - $28,000 - $24,000; AO - $16,000 - $200,000	24,000 - 96,000 ft^2	Not Provided	Not Provided	Not Provided
Multiple (6) Dry Cleaner Sites (Chemical Oxidation)	DI: Potassium Permanganate systems - $105,000 - $230,000, Hydrogen Peroxide - $110,000 - $170,000	400 - 7,900 ft^2 x 30 - 45 ft in depth	Not Provided	Not Provided	Not Provided
Multiple (5) Dry Cleaner Sites (Multi-Phase Extraction; Pump and Treat)	DI - $60,000 - $245,000	6,000 - 150,000 ft^3	Former Big B Cleaners - 215 lbs; Former Sta-Brite Cleaners - estimated 150 lbs during first 3 months; Koretizing Cleaners - 24 lbs; Nu Way II Cleaners - 90 lbs	Not Provided	Not provided
***Ex Situ* Groundwater Treatment**					
Commencement Bay South Tacoma Channel Superfund Site, Tacoma, WA (Pump and Treat)	Pump and Treat: C - $1.8 million (through May 2000); AO - $0.41 million (2000)	450 million gallons (through May 2000)	Pump and Treat - 15,000 lbs (through December 2000); SVE - 54,100 lbs	Not Provided	Not Provided

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

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment [1,2]	Key Factors Potentially Affecting Technology Costs
Union Chemical Company Superfund Site, South Hope, ME (Pump and Treat)	C - $9.5 million; AO (avg. for Pump and Treat and SVE systems) - $0.6 million; AO (avg. for *In Situ* Chemical Oxidation) - $0.15 million	Groundwater - 8.4 million gallons; Soil - 48,000 yd^3	9,600 lbs	Not Provided	Not Provided
***Ex Situ* Debris/Solid Waste Treatment**					
Hanford Site, C Reactor, Richland, WA (Surface Treatment)	P - $64,000 for 2,044 nozzle assemblies	Demonstration test - 9 nozzle assemblies, 196 m^2	Not Provided	Not Provided	Not Provided
Hanford Site, Richland, WA (Surface Treatment)	P - $49,000 for 1,956 lead bricks at the site	78 lead bricks, each 5 cm x 10 cm x 20 cm	Not Provided	Not Provided	Not Provided
Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID (Surface Treatment)	C - $390,000; Mobilization/ Demobilization cost - $2,455	60 ft^2	Not Provided	Operation - $37.41/$ft^2$; Waste Disposal - $150/$ft^2$	The robotic wall scabbler was estimated to be less expensive than the baseline technology for projects larger than 1,500 ft^2 with average wall sizes > 60 ft^2
Containment					
Marine Corps Base Hawaii, Kaneohe Bay, HI (Alternative Landfill cover)	Not Provided	Not Provided	Not Provided	C - $50,000 - $100,000/ac (estimate)	Not Provided
Naval Shipyard Long Beach, CA (Alternative Soil Pile Cover)	Total - $25,000	11,000 yd^3	Not Provided	P - $0.05 - $0.12/$ft^2$ for an active pile; $0.04 - $0.05/$ft^2$ for an inactive pile	Not Provided

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&D = design and development, D = Demonstration-scale costs, P = Projected full-scale costs.

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IN SITU SOIL TREATMENT ABSTRACTS

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

<table>
<tr><td colspan="2">Site Name:
Abe’s Main Street Cleaners; Donaldson’s Drycleaners; Dry Clean USA; One Price Drycleaners; Sir Galloway Dry Cleaners; Stuart Cleaners & Tailors; The Dry Cleaner</td><td>Location:
Abe’s Main Street Cleaners, Portland, OR; Donaldson’s Drycleaners, WI; Dry Clean USA, Orlando, FL; One Price Drycleaners, Sunrise, FL; Sir Galloway Dry Cleaners, Miami, FL; Stuart Cleaners & Tailors, Stuart, FL; The Dry Cleaner, Alamonte Springs, FL</td></tr>
<tr><td colspan="2">Period of Operation:
Abe’s Main Street Cleaners - 1998 (dates not specified)
Donaldson’s Drycleaners - Not specified
Dry Clean USA - April, 1999 to December, 2000
One Price Drycleaners - February, 2000 to August, 2000
Sir Galloway Dry Cleaners - January, 2000 to July, 2000
Stuart Cleaners & Tailors - January, 2000 to July, 2000
The Dry Cleaner - March, 1999 to September, 1999</td><td>Cleanup Authority:
State</td></tr>
<tr><td colspan="2">Purpose/Significance of Application:
Use of soil vapor extraction to remediate soil contaminated with chlorinated solvents at drycleaning sites</td><td>Cleanup Type:
Full scale</td></tr>
<tr><td colspan="2">Contaminants:
Chlorinated Solvents
• Concentrations of PCE in soil varied among the sites and ranged from 1 to 1,000 mg/kg. Some sites reported other chlorinated organics in the soil such as TCE, cis-1,2-DCE and VC
• Concentrations of PCE on groundwater varied among the sites and ranged from 0.003 to 55 mg/L. Some sites reported other chlorinated organics in the soil such as TCE, cis-1,2-DCE and VC. Two site reported that DNAPLs were present or likely to be present.</td><td>Waste Source:
Waste and wastewater from drycleaning operations</td></tr>
<tr><td rowspan="2">Contacts:
Varied by site</td><td colspan="2">Technology:
SVE
• SVE systems consisted of from 1 to 14 vapor extraction wells applying a vacuum of 19 to 70 inches of water and drawing 80 to 290 scfm of soil vapor at depths from 0.5 to 40 feet bgs. Two system also had air injection wells.
• At three sites pump and treat of contaminated groundwater was also conducted. The groundwater pump and treat continued operation for an unspecified period of time after the SVE system was shut down.
• At two sites, prior to SVE, excavation of hot spots was performed. At one of those sites the excavation was followed by backfilling and capping with asphalt to minimize infiltration of surface water into the contaminated areas.</td></tr>
<tr><td colspan="2">Type/Quantity of Media Treated:
Soil</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
• Soil cleanup goals were based on state regulatory goals
• Five sites had a soil cleanup goal of 30 mg/kg leachable PCE; one site had a soil cleanup goal 0.3 mg/kg for PCE.</td></tr>
<tr><td colspan="3">Results:
• All of the sites reported that SVE effectively removed PCE from soils
• The amounts of VOCs removed by the SVE systems ranged from 2 to7 pounds</td></tr>
<tr><td colspan="3">Costs:
Design and implementation costs for SVE systems ranged from $30,000 to $160,000; annual O&M costs for SVE systems ranged from $26,000 to $67,000</td></tr>
</table>

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

Description:
SVE was conducted at six drycleaner sites contaminated with chlorinated organic compounds from drycleaning operations. All of the sites reported that SVE effectively removed PCE from soils, with the amount of VOCs removed ranging from 2 to 7 pounds. Reported design and implementation costs for the SVE systems ranged from $30,000 to $160,000 and reported annual O&M costs ranged from $26,000 to $67,000.

Photocatalytic Reactor for Treatment of SVE and MPE Off-Gas at the Stamina Mills Superfund Site, North Smithfield, RI

Site Name:
Stamina Mills Superfund Site

Location:
North Smithfield, RI

Period of Operation:
August - October, 1999

Cleanup Authority:
Superfund Remedial Action

EPA Contact:
Mr. Vince Gallardo, Project Manager
U.S. EPA
National Risk Management Research Laboratory (NRMRL)
26 West Martin Luther King Drive
Cincinnati, OH 45268
Phone: (513) 569-7176
Fax:: (513) 569-7620
E-mail: gellardo.vincente@epa.gov

Purpose/Significance of Application:
Field demonstration of a photocatalytic reactor to treat off-gas from soil vapor extraction (SVE) and multi-phase extraction (MPE)

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated VOCs
- 94% of the contaminant mass in off-gas was TCE

Waste Source:
Off-gas from SVE and MPE

Technology:
Photocatalytic oxidation
- The contaminated air stream flows into the reactor where VOCs are adsorbed onto the surface of a proprietary catalyst that is continuously illuminated with UV light, oxidizing the VOCs.
- The unit operated at flow rates ranging from 490 to 600 scfm.
- The average power consumption was 15 kilowatts.

Type/Quantity of Media Treated:
Off-gas

Regulatory Requirements/Cleanup Goals:
- Contaminant removal efficiency (CRE) of 95% or higher for TCE
- Demonstrate effective TCE removal over an extended operational period (numerical goal not specified).
- State emissions standards for VOC emissions from the water scrubber following the photocatalytic reactor below the Rhode Island emissions standard for TCE and chloroform of 0.02 and 0.002 pounds per hour, respectively

Results:
- The observed CRE for TCE was 99.6%
- TCE emissions rom the water scrubber following the photocatalytic reactor ranged from 0.00039 to 0.0023 pounds per hour. TCE concentrations ranged from 0.038 to 0.19 ppmv.
- Chloroform emissions from the water scrubber following the photocatalytic reactor ranged from 0.00041 to 0.0050 pounds per hour

Costs:
- No information about costs was provided

Photocatalytic Reactor for Treatment of SVE and MPE Off-Gas at the Stamina Mills Superfund Site, North Smithfield, RI (continued)

Description:
The Stamina Mills Superfund site is a former textile manufacturing facility. Spills of solvents used to clean fabrics manufactured at the plant resulted in contamination of soil and groundwater. SVE and MPE systems are currently operating at the site to clean up the contamination.

A demonstration test of a photocatalytic oxidation system was conducted under the U.S. EPA Superfund Innovative Technology Evaluation Program (SITE). Off-gas from the SVE and MPE systems was treated using the photocatalytic oxidation system from August to October, 1999. Treatment goals for TCE were met. The vendor indicated that chloroform emissions from the scrubber could be reduced through the use of alternative photocatalysts or reactor configurations.

Natural Pressure-Driven Passive Bioremediation at Castle Airport, Merced, CA

Site Name:
Castle Airport (Formerly Castle Air Force Base)

Location:
Merced, CA

Period of Operation:
March 1998 - October 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Field demonstration of natural pressure-driven passive bioventing of petroleum-contaminated soil

Cleanup Type:
Field demonstration

Contaminants:
Total Petroleum Hydrocarbons (TPH), BTEX
- TPH concentrations in soil as high as 28,000 mg/kg
- BTEX concentrations in soil as high as 279 mg/kg

Waste Source:
Spills and leaks of jet fuels and gasoline

Site Contact:
Sherrie Larson, Project Manager and Principal Investigator
Phone: (805) 982-4826
E-mail: larsonsl@nfesc.navy.mil

Treatment Technology Contact:
Michael B. Phelps
Parsons Engineering Science, Inc.
Phone: (510) 891-9085
E-mail: michael_phelps@parsons.com

Technology:
Natural Pressure-Driven Passive Bioventing
- Uses the force generated by normal daily fluctuations in atmospheric conditions to replace a powered blower for injecting air into the subsurface
- A single vent well was installed to a depth of 65 feet with three isolated 10-foot screened sections to evaluate airflow rates in three different lithologic zones
- The radius of influence of the bioventing well was estimated at 42 feet after seven weeks
- The daily airflow rates ranged from 27 to 9300 ft^3 per day and averaged 3,400 ft^3 per day

Type/Quantity of Media Treated:
Soil
- Upper 20 ft of subsurface comprised of silty sand overlying a laterally continuous silt layer between 20 and 25 ft
- Soil moisture - average about 6%

Regulatory Requirements/Cleanup Goals:
- Goals of the demonstration included achieving consistent air flow rate to vadose zone greater than 1 cfm and 1,200 cubic feet per day and a radius of influence greater than 10 feet
- No specific cleanup levels were identified for the demonstration

Results:
- Air supply during demonstration consistently exceeded goals of 1 cfm and 1,200 cubic feet per day; ranged from 27 to 9300 cubic feet per day (cfd), and averaged 3,400 cfd
- The radius of influence was estimated to be 42 feet after seven weeks, exceeding the goal of 10 feet.
- As areas near the well are remediated and the oxygen demand is satisfied, the predicted radius of influence would be expected to be 85 feet, comparing favorably to conventional bioventing radius of influence of 110 feet

Costs:
- The estimated cost of a full-scale passive bioventing system was $1.93 per cubic yard of soil treated. The cost of conventional bioventing was estimated at $2.09 per cubic yard
- Passive bioventing would require the use of 1.5 times as many wells as conventional bioventing, and a treatment time of 4 years instead of 3 years at the Castle Airport Site, however an overall reduction in costs would be achieved by eliminating the capital cost of blowers and the O&M cost of powering the blowers.

Natural Pressure-Driven Passive Bioremediation at Castle Airport, Merced, CA (continued)

Description:
A demonstration of natural pressure-driven passive bioventing was performed at Castle Airport in Merced, CA The petroleum oil and lubricants fuel farm area was the bulk fuel storage and distribution facility for the former AFB located at the site. Soil and groundwater contamination resulted from leaking underground storage tanks and fuel distribution lines and surface spills. The Department of Defense Environmental Security Technology Certification Program (ESTCP), the Air Force Research Laboratory, and Naval Facilities Engineering Service Center, and the Air Force Center for Environmental Excellence (AFCEE) cooperated in conducting the demonstration.

Natural pressure-driven passive bioventing is similar to conventional bioventing with the exception that it uses the force generated by normal daily fluctuations in atmospheric conditions to replace a powered blower for injecting air into the subsurface. During the demonstration, six tests of natural pressure-driven passive bioventing were performed over a six month period. A single well installed to a depth of 65 feet achieved an average daily air flow rate to the vadose zone of 3,400 cubic feet and a radius of influence of 42 feet. As areas near the well are remediated and the oxygen demand is satisfied, the predicted radius of influence would be expected to be 85 feet, comparing favorably to conventional bioventing radius of influence of 110 feet. The projected cost of a full-scale passive bioventing system was $1.93 per cubic yard of soil treated, compared to $2.09 per cubic yard for conventional bioventing.

Phytoremediation at the Magic Marker and Fort Dix Sites, NJ

<table>
<tr><td colspan="2">Site Name:
Magic Marker and Fort Dix</td><td>Location:
Magic Marker, Trenton, NJ; Small Arms Firing Range (SAFR) 24, Fort Dix, NJ</td></tr>
<tr><td>Period of Operation:
Magic Marker - May 1997 to November 1998
Fort Dix - April 2000 to October 2000</td><td>Cleanup Authority:
Not identified</td><td>EPA Contact:
Steven Rock
U.S. EPA NRMRL
5995 Center Hill Avenue
Cincinnati, OH 45224
Phone: (513) 569-7149
E-mail: rock.steven@epa.gov</td></tr>
<tr><td colspan="2">Purpose/Significance of Application:
Magic Marker - Demonstration of phytoremediation treatment of lead in surface soil
Fort Dix - Demonstration of the ability of phytoremediation treatment to reduce lead concentrations in soil following soil washing</td><td>Cleanup Type:
Field demonstration</td></tr>
<tr><td colspan="2">Contaminants:
Metals - Lead
Magic Marker:
• Lead in soil as high as 57,114 milligrams per kilogram (mg/kg)
Fort Dix:
• Mean lead concentration in soil of 516 mg/kg</td><td>Waste Source:
Lead-acid battery manufacturing - Magic Marker
Small arms firing range - Fort Dix</td></tr>
<tr><td rowspan="2">Technology Vendor:
Dr. Michael Blaylock
Edenspace Systems Corporation
15100 Enterprise Court, Suite 100
Dulles, VA 20151-1217
Phone: (703) 961-8939
E-mail: SoilRx@aol.com</td><td colspan="2">Technology:
Phytoremediation
Magic Marker Site Phytoremediation
• Changes in lead levels in a treatment plot measuring 77 feet by 50 feet were compared to those in a control plot measuring 40 feet by 30 feet during the demonstration.
• Two crops of Indian Mustard (Brassica juncea) were planted and harvested in 1997. A third crop of sunflowers (Helianthus annus) was grown and harvested in 1998.
• Plant tissue samples were collected and analyzed to determine whether the plants were able to bioaccumulate lead.
Fort Dix Site Phytoremediation
• The demonstration was conducted in a 1.25 acre ex situ lined treatment cell.
• Excess water from irrigation and precipitation was collected in a lined catchment basin and recirculated for irrigation as needed.
• Three crops were planted harvested during the 2000 growing season: (1) Indian Mustard (Brassica juncea), (2) sunflowers (Helianthus annus), and (3) a mixture of rye (Secale cereale) and barley (Hordeum vulgare).</td></tr>
<tr><td colspan="2">Type/Quantity of Media Treated:
Soil
• Magic Marker - in situ soil, 77 feet by 50 feet by 6 inches deep
• Fort Dix - ex situ soil, 1.25 acres by 12 inches deep</td></tr>
</table>

Phytoremediation at the Magic Marker and Fort Dix Sites, NJ (continued)

Regulatory Requirements/Cleanup Goals:
Magic Marker:
- Achieve average lead concentrations in above-ground plant tissue of greater than 200 mg/kg on a dry weight basis
- Demonstrate a 15% reduction in dry weight soil lead concentrations where initial concentrations exceeded 400 mg/kg

Fort Dix:
- Achieve the NJDEP industrial total lead concentration goal of 600 mg/kg or the residential goal of 400 mg/kg
- Reduce soil leachable lead concentrations to 5 milligrams per liter (mg/L), as measured by the EPA Toxicity Characteristic Leaching Procedure (TCLP)

Results:
Magic Marker:
- Above-ground plant tissue lead concentrations on a dry weight basis in mg/kg were: *Brassica juncea* crop 1- 830; *Brassica juncea* crop 2 - 2,300; *Helianthus annus* - 400
- A 17% reduction in dry weight soil lead concentrations was achieved where initial concentrations exceeded 400 mg/kg

Fort Dix:
- The average lead concentration in the treated surface soil (0 to 6 inches in depth) was 182 mg/kg, which was below the cleanup goal of 400 mg/kg
- The average lead concentration in the treated subsurface soil (6 to 12 inches in depth) was 398 mg/kg, which was below the cleanup goal of 400 mg/kg
- Information on leachable lead concentrations in the soil were not provided
- The demonstration generated 110,000 gallons of drainage water containing 160 mg/L lead
- Above-ground plant tissue lead concentrations on a dry weight basis in mg/kg were: *Brassica juncea* crop 1- 1,437; *Helianthus annus* crop 2 - 1,675; *Secale cereale* and *Hordeum vulgare* crop 3- 4,395

Costs:
- No specific costs were provided for the demonstrations
- The estimated cost per cubic yard for phytoremediation of soil ranged from $23.87 for a 1-crop *in situ* treatment with low biomass disposal costs to $127.40 for a 3-crop *ex situ* treatment with high biomass disposal

Description:
The seven-acre Magic Marker site located in Trenton, NJ is an urban area "Brownfield." The site was used for lead-acid battery manufacturing from 1947 to 1979 and then by the Magic Marker facility up until its closure in 1987. A demonstration was performed under the Superfund Innovative Technology Evaluation (SITE) program between May 1997 and November 1998 to determine whether phytoremediation could effectively reduce lead contamination in surface soils. The demonstration included planting and harvesting two crops of Indian Mustard (*Brassica juncea*) in 1997 and a crop of sunflowers (*Helianthus annus*) in 1998. The demonstration achieved its objectives of 200 mg/kg lead in above-ground plant tissues and reduction of soil lead concentrations by 15%.

The soil at SAFR 24 at Fort Dix, NJ was determined to be contaminated with lead, including spent bullets and bullet fragments. A joint demonstration with the U.S. Department of Defense RangeSafe Technology Demonstration Initiative (RTDI) and the SITE program was performed to evaluate the use of soil washing followed by phytoremediation to treat lead in soil at the site. After soil washing, the soil was placed in a 1.25 acre *ex situ* lined treatment cell, where the phytoremediation was conducted. The demonstration included planting and harvesting three crops during the 2000 growing season: (1) Indian Mustard (*Brassica juncea*), (2) sunflowers (*Helianthus annus*), and (3) a mixture of rye (*Secale cereale*) and barley (*Hordeum vulgare*). The demonstration achieved its treatment objective of reducing lead concentrations to below 400 mg/kg.

In Situ Electrokinetic Remediation at the Naval Air Weapons Station, Point Mugu, CA

Site Name:
Naval Air Weapons Station (NAWS) Point Mugu Site 5

Location:
Point Mugu, CA

Period of Operation:
March 1998 - October 1998 (total of 22 weeks of operation)

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstrate the use of electrokinetics for treatment of heavy metals in soil

Cleanup Type:
Field demonstration

Contaminants:
Heavy metals
- Surface sampling indicated chromium at up to 25,100 mg/kg (TCLP ND) and cadmium at up to 1,810 mg/kg (TCLP 10.5 mg/L)

Waste Source:
Discharges from electroplating and metal finishing operations

Technical Contacts:
Steve Granade
NAWS Point Mugu

Brian Harre
Naval Facilities Engineering Service Center

Technology Vendor:
Lynntech, Inc.

Technology:
Electrokinetic remediation
- System included an array of electrode wells, power supply and control system , monitoring system, process piping to distribute chemicals to and extract contaminants from electrode wells, and off-gas treatment system
- Electrode array consisted of a series of 24 anode and 14 cathode wells for two lagoons in the test cell; anode wells were 4 inch slotted PVC casings wrapped in linen fabric; anodes were rod-shaped and constructed of titanium with iridium oxide coating; cathode wells were 3-inch porous ceramic casings; cathodes were 2-inch wide strips of stainless steel mesh
- Citric acid was used as a soil amendment to enhance contaminant mobility
- Current density - 0.1 mA/cm^2 for about 3 months; increased to 0.2 mA/cm^2 in effort to raise contaminant movement; after six week shutdown to review project, current density further increased to 0.33 mA/cm^2 with a corresponding decrease in the size of the treatment cell to one lagoon
- Prior to field demonstration, extensive laboratory testing was conducted to assess the potential effectiveness of electrokinetic extraction at the site; results indicated the technology could be successfully applied at the demonstration site

Type/Quantity of Media Treated:
Soil and Sediment
- Approximately 0.5 acres
- 85% sand, 7% gravel, 6% silt, and 1% clay
- pH of 5.84, TOC of 6,390 mg/kg, hydraulic conductivity of 0.045 cm/sec, cation exchange capacity of 3.9

Regulatory Requirements/Cleanup Goals:
- Site target cleanup levels are State of California limits for chromium of <2,500 mg/kg and cadmium of 100 mg/kg

Results:
- After 22 weeks of operation, contaminant reduction goals were not met; a pH front was just beginning to develop, with limited contaminant movement; the demonstration was suspended in October 1998
- Control of electrokinetically mobilized contaminants within the confined and unconfined treatment areas could not be assessed due to the poor performance of the technology.
- There was an increase in soil VOCs, primarily due to trihalomethane production resulting from Cl buildup in the anode wells
- The high chloride concentration of the groundwater was the main site characteristic that lengthened the time required to extract contaminants from the soil

In Situ Electrokinetic Remediation at the Naval Air Weapons Station, Point Mugu, CA (continued)

Costs:

- Projected full-scale costs of $1,193/CY were extrapolated from the costs incurred for the field demonstration
- The total projected cost was $1,193,050 for treatment of 1,000 CY, consisting of $890,988 for capital and $302,062 for O&M

Description:

Site 5 at NAWS Point Mugu was used for electroplating and metal finishing operations. Wastewater was discharges to unlined lagoons, resulting in soil and groundwater contamination at the site. A demonstration of electrokinetic remediation was performed from March to October 1998 to treat soil at the site. The demonstration was conducted by the U.S. Army Environmental Center (USAEC), Engineer Research and Development Center (ERDC); the Environmental Security Technology Certification Program (ESTCP) and Southwest Division, Naval Facilities Engineering Command.

The electrokinetic remediation system demonstrated consisted of a series of anode wells and cathode wells arrayed in the test cell. Citric acid was used as a soil amendment to enhance contaminant mobility. The initial current density applied to the system was increased after about three months of operation in an effort to increase contaminant mobility. The current density was further increased with a corresponding decrease in the size of the test area in additional efforts to increase contaminant mobility. However, after 22 weeks of operation, the pH front was just beginning to appear with limited contaminant removal; the demonstration was suspended in October 1998. The bench-scale tests did not accurately reflect the effects of site conditions on performance. A projected full-scale cost for use of the technology was estimated as more than $1,100/cubic yard of soil treated.

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EX SITU SOIL TREATMENT ABSTRACTS

Biocell Technology, *Ex Situ* Bioremediation of Petroleum-Contaminated Soils, Port Hueneme, CA

Site Name:
Naval Construction Battalion Center's (NCBC) Hydrocarbon National Test Site

Location:
Port Hueneme, CA

Period of Operation:
October 1996 - January 1997 (105 days of operation)

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Field demonstration of an ex-situ bioremediation technology to treat small quantities of petroleum-contaminated soils

Cleanup Type:
Field demonstration

Contaminants:
Total Petroleum Hydrocarbons (TPH)
- Concentrations up to 736 mg/kg in soil

Waste Source:
Spills and leaks from fuel storage and vehicle maintenance

Navy Contacts:
Mr. Dharam Pal
Phone: (805) 982-1671
E-mail: pald@nfesc.navy.mil

Mr. Jeff Heath
Phone: (805) 982-1600
E-mail: heathjc@nfesc.navy.mil

Technology:
Ex Situ Bioremediation - Composting
- Petroleum-contaminated soils were placed in a 10 cubic yard biocell, constructed using a commercial roll-off dumpster; container covered with an impermeable liner to prevent the release of VOCs and soil and to protect the system from precipitation and wind
- Blower used to draw air through perforated pipes installed under the soil
- Leachate collection system used to capture excess moisture
- Off-gas treated using granular activated carbon; blower used to create a slight vacuum in the system to reduce VOC emissions

Type/Quantity of Media Treated:
Soil
- 10 cubic yards of soil treated

Regulatory Requirements/Cleanup Goals:
- The objectives of the demonstration included evaluating the effectiveness of a biocell for treating petroleum-contaminated soils
- No specific cleanup goals were identified for the demonstration

Results:
- After 105 days of biocell operation, TPH concentrations were reduced from 736 mg/kg to 147 mg/kg

Costs:
- Units costs were estimated for operating a 40 cubic yard biocell. The estimated cost per cubic yard of soil treated, amortized over 5 years with three operations per year, were $40.83 for one biocell, $36.75 for two biocells, and $35.56 for 3 biocells

Biocell Technology, Ex Situ Bioremediation of Petroleum-Contaminated Soils, Port Hueneme, CA (continued)

Description:
Navy installations generate petroleum-contaminated soils from a variety of operations including fuel storage, vehicle maintenance and repair, and training areas where fuel has been spilled on the ground. For small quantities of petroleum-contaminated soil, off-site disposal can be expensive. The biocell technology, an *ex situ* bioremediation system, provides a potential alternative to off-site disposal for treating small quantities of soil contaminated with low to intermediate concentrations of petroleum hydrocarbons.

The Naval Facilities Engineering Service Center conducted a demonstration of the biocell technology for petroleum-contaminated soils at the Naval Construction Battalion Center's (NCBC) Hydrocarbon National Test Site in Port Hueneme, California. The system used for the demonstration was a 10 cubic yard biocell built using a commercially available roll-off container. After 105 days of operation, TPH concentrations in the soil were reduced from 736 mg/kg to 147 mg/kg. The estimated unit costs for operating a 40 cubic yard biocell ranged from about $35 to $40 per cubic yard of soil treated, depending on the number of biocells. Several benefits were identified for biocell technology including relatively easy design and construction, potential applicability to a wide range of site conditions, and biocells may be cost-competitive with off-site disposal.

Ex Situ Bioremediation of Soil at Two Drycleaner Sites, Various Locations

Site Name: Peerless Cleaners; Stannard Launders and Dry Cleaners	**Location:** Peerless Cleaners, WI; Stannard Launders and Dry Cleaners, WI
Period of Operation: Peerless Cleaners - 2 years, date not specified Stannard Launders and Dry Cleaners - not specified	**Cleanup Authority:** State
Purpose/Significance of Application: Use of biopiles to treat contaminated soil from drycleaning operations	**Cleanup Type:** Full scale
Contaminants: Chlorinated Solvents, Naphthalene, Ethylbenzene, Xylenes, Toluene • Chlorinated solvents in soil - PCE (12,000 mg/kg), TCE, DCE, DCA (34 mg/kg)	**Waste Source:** Waste and wastewater from drycleaning operations
Contacts: Varied by site	**Technology:** *Ex situ* bioremediation in biopiles • Soil was excavated and transported off-site for bioremediation in biopiles. The treatments included adding microorganisms to the soil and passing air through the piles to stimulate biological growth and biodegradation of contaminants. Following bioremediation, the soil was disposed in a landfill. • At the Peerless Cleaners site, 18 tons of soil was excavated from areas with high contaminant concentrations and treated in biopiles. Areas with lower contaminant concentrations were treated using an *in situ* passive SVE system. • At the Stannard Launders and Dry Cleaners site, 594 tons of soil was excavated and treated in biopiles. **Type/Quantity of Media Treated:** Soil • Peerless Cleaners - 18 tons • Stannard Launders and Dry Cleaners - 594 tons

Regulatory Requirements/Cleanup Goals:
- Specific cleanup levels not identified; goal of cleanup was to remove as much of the contamination source as possible

Results:
- Peerless Cleaners - Concentrations of chlorinated organic compounds were reduced to non-detect levels.
- Stannard Launders and Dry Cleaners - Information was not available on contaminant concentrations in the soil and groundwater at the site following remediation.

Costs:
Design and implementation costs
- Peerless Cleaners - $14,000
- Stannard Launders and Dry Cleaners - $39,000

Description:
Ex situ remediation of soil using bioremediation in biopiles was performed at 2 drycleaner sites in Wisconsin. Soils were contaminated with chlorinated solvents and other organics from drycleaning operations. For the Peerless Cleaners site, concentrations of chlorinated organic compounds were reduced to non-detect levels.

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Thermal Desorption at the Cape Fear Superfund Site, Fayetteville, North Carolina

Site Name:
Cape Fear Superfund Site

Location:
Fayetteville, North Carolina

Period of Operation:
July 1998 - April 1999

Cleanup Authority:
CERCLA
- ROD signed June 30, 1989

EPA Contact:
Jon Bornholm
EPA Region 4
61 Forsyth Street, S.W.
Atlanta, GA 30303-8960
Telephone: (404) 562-8820
Fax: (404) 562-8788
E-mail: bornholm.jon@epa.gov

Purpose/Significance of Application:
Thermal desorption of a large volume of soil contaminated with wood preserving chemicals containing PAHs, benzene, and metals

Cleanup Type:
Full scale

Contaminants:
PAHs , arsenic, chromium, benzene

Waste Source:
Discharges from wood preserving operations

PRP Contractor:
Bruce Ford
Bechtel Environmental
Millennium Construction Contractors
P.O. Box 4777
Fort McMurry, Alberta, Canada T9H 5G3
E-mail: bford@suncor.com

Treatment 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:
Thermal desorption
- Low temperature thermal desorption system owned by Williams Environmental Inc - direct-heated countercurrent rotary dryer fired by a 49 million BTU/hour burner, feed metering unit, baghouse, thermal oxidizer, and control unit that housed the controls, data logger, and analyzers.
- Average system throughput of 43.3 tons/hr
- Residence time - 20 minutes
- Average soil exit temperature - 851 °F

Type/Quantity of Media Treated:
Soil
- 170,300 tons of soil treated
- Silty clays and sand
- Moisture content - <20% (shallow soil); 20% to 40% (deep soil)

Regulatory Requirements/Cleanup Goals:
Cleanup goals for soil specified in the ROD:
- Total carcinogenic PAHs (sum of benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene.) - 2.5 mg/kg
- Total PAHs (total carcinogenic PAHs plus the sum of acenaphthene, acenaphthalene, anthracene, benzo(g,h,i)perylene, fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene) - 100 mg/kg
- Benzene - 0.005 mg/kg, arsenic - 94 mg/kg, chromium - 88 mg/kg

Results:
- With two exceptions, all soil met the cleanup goals after initial treatment in the desorber
- Approximately 1,106 tons of soil failed to meet the cleanup goal for benzene, and were retreated to meet the cleanup goal
- Of the 378 piles of treated soil, only one pile had a level of chromium, 89.3 mg/kg, that exceeded the cleanup goal of 88 mg/kg. According to the RPM, EPA allowed the contractor to backfill this material without further treatment.

Thermal Desorption at the Cape Fear Superfund Site, Fayetteville, North Carolina (continued)

Costs:

- The total cost for the thermal treatment application at this site was $9,888,575, including $1,800,529 in capital cost and $8,088,046 on O&M costs
- The unit cost for this application was $58/ton based on treating 170,300 tons of soil

Description:

The Cape Fear Superfund Site is located on 41 acres in Fayetteville, North Carolina. The site was operated as a wood preserving facility from 1953 to 1983, first using a creosote process and, starting in 1970, using a copper-chromated-arsenate (CCA) process. Liquid and sludge wastes generated by both of these processes were pumped into a drainage ditch and an unlined lagoon. Investigations at the site by EPA and the State of North Carolina showed that soil at the site was contaminated with polycyclic aromatic hydrocarbons (PAHs), benzene, and metals including arsenic and chromium. A Record of Decision (ROD), signed in June 1989, specified excavation and soil washing to address the soil contamination from the drainage ditch and unlined lagoon. However, initial soil washing operations did not meet the cleanup goals for carcinogenic PAHs. and EPA made the decision to implement the contingent remedy, low temperature thermal desorption.

The thermal treatment system used for this application was a low temperature thermal desorption system owned by Williams Environmental Services, Inc. A demonstration test was performed July 20 - 22, 1998 during which 1,900 cubic yards of soil were treated. Full-scale thermal desorption was conducted from July 1998 to April 1999 during which 170,300 tons of soil were treated. The total costs for the thermal treatment application $9,888,575 ($58/ton of soil treated). This completed project involved the largest quantity of soil treated using thermal desorption the U.S. at the time the project was performed.

Thermal Desorption at the Lipari Landfill, Operable Unit 3, Pitman, New Jersey

Site Name:
Lipari Landfill, Operable Unit 3

Location:
Pitman, New Jersey

Period of Operation:
September 1994 - September 1995

Cleanup Authority:
CERCLA
- ROD signed July 11, 1988

EPA Remedial Project Manager:
Fred Cataneo
EPA Region 2
290 Broadway, 19th Floor
New York, NY 10007
Telephone: (212) 637-4428
Fax: (212) 637-4393
E-mail: cataneo.fred@epa.gov

Purpose/Significance of Application:
Thermal desorption of a soil contaminated with VOCs, SVOCs, and metals

Cleanup Type:
Full scale

Contaminants:
VOCs, SVOCs, and Metals
- VOCs - trichloroethene, chlorobenzene, acetone, benzene, toluene
- SVOCs - bis (2-chloroethyl) ether, benzoic acid, acid/extractables, base/neutral extractables
- Metals - antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, selenium, molybdenum, mercury, nickel, silver, thallium, vanadium, zinc

Waste Source:
Disposal of a variety of household, chemical, and other industrial wastes in a landfill

PRP Contractor:
Philip R. DeLuca
Sevenson Environmental Services, Inc.

2749 Lockport Rd.
Niagara Falls, NY 14305
Telephone: (716) 284-0431
E-mail: pdeluca@sevenson.com

Treatment 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:
Thermal desorption
- Low temperature thermal desorption system owned by Williams Environmental Inc - direct-heated countercurrent rotary dryer fired by a 49 million BTU/hour burner, feed metering unit, baghouse, thermal oxidizer, and control unit that housed the controls, data logger, and analyzers.
- Average system throughput - 311 tons/day (first 4 months); 529 tons/day (remainder of project)
- Residence time - 20 minutes
- Average soil exit temperature - 733 °F (before October 21, 1994); 850 °F (after October 21, 1994)

Type/Quantity of Media Treated:
Soil
- 80,000 tons of soil treated
- Moisture content - 20-30%

Regulatory Requirements/Cleanup Goals:
Cleanup goals for soil:
- Total VOCs - 1 mg/kg
- SVOCs - bis (2-chloroethyl) ether (0.011 mg/kg), acid extractables (50 mg/kg), and base/neutral extractables (10 mg/kg)
- Metals (total) mg/kg - antimony (10), arsenic (20), barium (400), beryllium (1), cadmium (3), chromium (100), copper (170), lead (500), selenium (4), molybdenum (1), mercury (1), nickel (100), silver (5), thallium (5), vanadium (100), zinc (35)
- Metals (TCLP) mg/L - arsenic (5), barium (100), cadmium (1), chromium (5), lead (5), mercury (0.2), selenium (1), silver (5

Emission limits were identified by the NJ DEP for organic and inorganic compounds and air quality parameters, including a DRE of 99.99%

Thermal Desorption at the Lipari Landfill, Operable Unit 3, Pitman, New Jersey (continued)

Results:
Available performance data for this application is limited to the results of the performance test conducted in May 1995. The results show that, with the exception of molybdenum, all soil cleanup targets were met during the test. According to the vendor, the elevated concentrations of molybdenum were due to its use in the grease on the front-end loader used to transport soil.

While no concentration data were provided for treated soil other than for the performance test, the vendor reported that, ninety-five percent of the soil was treated to below the cleanup goals on the initial pass through the desorber. The soil that did not meet the cleanup goal for bis (2-chloroethyl) ether was retreated to meet the cleanup goal.

Costs:
- The total cost for the thermal treatment application at this site was $6,082,029, including $430,000 in capital cost and $5,019,292 in O&M costs
- The unit cost for this application was $68/ton based on treating 80,000 tons of soil

Description:
The Lipari Landfill (Lipari) site was used for disposal of a variety of household, chemical, and other industrial wastes from 1958 to 1971. Approximately 3 million gallons of liquid wastes and 12,000 cubic yards of solid wastes were disposed of in trenches originally excavated for sand and gravel. The wastes included solvents, paints and thinners, formaldehyde, dust collector residues, resins, and solid press cakes from the industrial production of paints and solvents. The Lipari Landfill was closed by the New Jersey Department of Environmental Protection in 1971 and added to the National Priorities List in September 1983. In July 1988, EPA signed a Record of Decision to clean up Operable Unit (OU) 3 (offsite contamination) at Lipari using thermal desorption for soil and sediment from a marsh area.

The thermal treatment system used for this application was a low temperature thermal desorption system owned by Williams Environmental Services, Inc. Thermal desorption was conducted at the site from September 1994 to September 1995, including a five month downtime to rebuild a baghouse used for treating the off-gas from the thermal desorber. A total of 80,000 tons of contaminated soil and sediment were treated during this application. The total costs for the thermal treatment application $6,082,029 ($68/ton of soil treated). The presence of elevated levels of sulfur pyrite in soil treated through the desorber caused a fire in the baghouse partway through the project. The fire destroyed the baghouse and delayed completion of the project by five months. The high moisture content of the soil (20 to 30%) obtained from the marsh limited the throughput, and lime was added to the soil to reduce the moisture content and improve material handling.

Thermal Desorption at the Reilly Industries Superfund Site, OU 3
Indianapolis, Indiana

<table>
<tr><td colspan="2">Site Name:
Reilly Industries Superfund Site</td><td>Location:
Indianapolis, Indiana</td></tr>
<tr><td>Period of Operation:
November 1996 - January 1997</td><td>Cleanup Authority:
CERCLA
• ROD signed September 1993</td><td>Remedial Project Manager:
Dion Novak
EPA Region 5 (SR-6J)
77 West Jackson Blvd.
Chicago, IL 60604-3507
Telephone: (312) 886-4737
E-mail: novak.dion@epa.gov</td></tr>
<tr><td colspan="2">Purpose/Significance of Application:
Thermal desorption of soil containing PAHs, benzene, toluene, and pyridine from coal tar refining and wood preserving.</td><td>Cleanup Type:
Full scale</td></tr>
<tr><td colspan="2">Contaminants:
PAHs , Pyridine, Benzene
• Soil concentrations as high as 3,794 mg/kg for PAHs, 5,673 mg/kg for pyridine, and 191 mg/kg for benzene</td><td>Waste Source:
Discharges from wood preserving and coal tar refinery operations</td></tr>
<tr><td rowspan="2">PRP Contractor:
Eric Medlin
Four Seasons Environmental, Inc.
P.O. Box 16590
Greensboro, NC 27416-0590
Telephone: (336) 273-2718
Fax: (336) 274-5798
E-mail: emedlin@fourseasonsenv.com

Treatment 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@wmsgrintl.com</td><td colspan="2">Technology:
Thermal desorption
• Low temperature thermal desorption system owned by Williams Environmental Inc - direct-heated countercurrent rotary dryer fired by a 49 million BTU/hour burner, feed metering unit, baghouse, thermal oxidizer, and control unit that housed the controls, data logger, and analyzers.
• Average system throughput - 20 to 22 tons/hr
• Residence time - 15 to 20 minutes
• Average soil exit temperature - 800 - 1000°F</td></tr>
<tr><td colspan="2">Type/Quantity of Media Treated:
Soil
• 3,700 tons of soil treated
• Moisture content - 15 to 30%</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
• Cleanup goals for soil specified in the ROD:
- Carcinogenic PAHs (benzo(a)pyrene equivalents) - 20 mg/kg
- Pyridine derivatives (510 mg/kg), pyridine (0.7 mg/kg), benzene (0.1 mg/kg), toluene (20 mg/kg)
• Stack gas emissions limits were specified for VOCs of 15 pounds per day</td></tr>
<tr><td colspan="3">Results:
• 28 of 33 batches met the cleanup goals after initial treatment in the desorber. Five batches (about 925 tons of soil) that did not meet the cleanup goal for pyridine were retreated to meet these standards
• Air emissions were monitored during the one run performance test and met applicable emission limits</td></tr>
</table>

Thermal Desorption at the Reilly Industries Superfund Site, OU 3 Indianapolis, Indiana (continued)

Costs:

- The total cost for the thermal treatment application at this site was $1,087,732, including $270,000 in capital cost and $659,130 in O&M costs
- The unit cost for this application was $251/ton based on treating 3,700 tons of soil

Description:

The 120-acre Reilly Industries Superfund site (Reilly), previously known as Reilly Tar & Chemical (Indianapolis Plant), is a former coal tar refinery and creosote wood treatment plant located in Indianapolis, Indiana. The site includes the following five waste disposal areas: the Lime Pond area; the Abandoned Railway Trench; the Former Sludge Treatment Pit; the Former Drainage Ditch; and the South Landfill and Fire Pond. The Reilly site was added to the National Priorities List (NPL) in 1984. Contaminants of concern in the soil included PAHs, benzene, toluene, and pyridine, including its derivatives. In September 1993, a record of decision (ROD) was signed for operable unit (OU) 2 to address the contaminated soil and sludge in the disposal areas. The ROD required treatment of 11,000 tons of soil on site using thermal desorption. An explanation of significant differences (ESD) was signed in October 1997 to modify the remedy for OU 2, reducing the quantity of soil to be treated to 3,700 tons

The thermal treatment system used for this application was a low temperature thermal desorption system owned by Williams Environmental Services, Inc. Between November 1996 and January 1997, a total of 3,700 tons of contaminated soil were treated. The presence of elevated BTU and moisture content of the soil limited the amount of material that could be processed through the desorber. Engineering modifications, including blending soil, modifying the desorber to promote heat transfer, and reducing the soil screening cutoff size, did not increase the throughput rate. The vendor was able to treat only about one-third of the contaminated soil originally intended to be treated on site with thermal desorption because of this change in site conditions. The remaining contaminated soil was shipped off site for treatment using a boiler or industrial furnace. The total costs for the thermal treatment application $1,087,732, ($251/ton of soil treated).

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IN SITU GROUNDWATER TREATMENT ABSTRACTS

DNAPL Bioremediation-RTDF at Dover AFB, Area 6, Dover, Delaware

Site Name:
DNAPL Bioremediation-RTDF at Dover AFB, Area 6

Location:
Dover, Delaware

Period of Operation:
May 1996 - March 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Demonstration of bioremediation to treat DNAPL in groundwater

Cleanup Type:
Field demonstration

Contaminants:
VOCs
- TCE,1,2-DCE
- Average TCE concentrations - 4,800 ug/L; average cis-1,2-DCE concentrations - 1,200 ug/L
- Estimated contaminant mass in demonstration area - 3.6 pounds

Waste Source:
Spills and disposal of solvent wastes from industrial operations at the site

RTDF Contact:
Dave Ellis
RTDF Steering Committee Chairperson
Dupont
Telephone: (302) 892-7445
E-mail: david.e.ellis@usa.dupont.com

DOE Contacts:
Don Maiers
Principal Investigator
INEEL
Telephone: (208) 526-6991
E-mail: dmi@inel.gov

Jim Wright
DOE EM50 Subsurface Contaminants Focus Area Manager
Telephone: (803) 725-5608
E-mail: jamesb.wright@srs.gov

Technology:
In Situ Bioremediation
- Demonstration conducted in two phases - one stimulating indigenous microorganisms, one using bioaumentation with an imported culture of microorganisms
- Three injection and three injection wells; aligned perpendicular to groundwater flow with extraction wells spaced 60 ft from injection wells to create recirculation area
- Sodium lactate added on a 7-day cycle; nutrients (ammonium phosphate and yeast extract) pulsed fed

Type/Quantity of Media Treated:
Groundwater
- Depth to groundwater - 10 to 12 ft
- Unconfined aquifer; hydraulic conductivity - 60 ft/day
- Total groundwater circulated during the demonstration - 2.7 million gal

Regulatory Requirements/Cleanup Goals:
No specific cleanup levels identified for the demonstration

Results:
- During the first phase (indigenous microbes), no degradation beyond DCE was observed
- After an initial lag period of 90 days, the augmenting culture began transforming DCE to vinyl chloride and ethene
- At the end of the demonstration, complete degradation of chlorinated solvents to ethene occurred
- Complete dechlorination of solvents occurred first between the injection well and the nearest monitoring well (about 4 ft)

Costs:
Estimated net present value of implementing ISB at Dover AFB - $596,000

DNAPL Bioremediation-RTDF at Dover AFB, Area 6, Dover, Delaware (continued)

Description:
Spills and waste disposal practices from historic maintenance and repair operations at the Dover AFB in Delaware had resulted in the contamination of soil and groundwater at the site with solvents, including TCE, PCE, and DCE. The Remediation Technologies Development Forum (RTDF) sponsored a demonstration of *in situ* bioremediation (ISB) at a site located in Area 6 of the Dover AFB in Delaware. Average TCE, DCE, and PCE concentrations in groundwater at Area 6 were 4,800 ug/L, 1,200 ug/L, and 3 ug/L, respectively.

The ISB system used for the demonstration included injection and extraction wells, a nutrient/substrate injection system, and a groundwater monitoring system. The demonstration, performed between May 1996 and March 1998, included two phases - one involving the stimulation of indigenous microorganisms; one using bioaugmentation with a culture from Largo, Florida. While no degradation beyond DCE was observed during the first phase using indigenous microbes, the addition of the culture from Florida resulted in the complete degradation of solvents to ethene. Costs to perform ISB at Dover AFB were based on the cost of the demonstration. The estimated net present value of implementing ISB at Dover AFB was $596,000. Better mechanisms for effective distribution of nutrients and substrate into low permeability zones of an aquifer was identified as a future development need to facilitate implementation of ISB.

Enhanced *In Situ* Bioremediation at Idaho National Engineering and Environmental Laboratory, Test Area North, Idaho Falls, Idaho

Site Name:
Idaho National Engineering and Environmental Laboratory, Test Area North

Location:
Idaho Falls, Idaho

Period of Operation:
1999 - 2000

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Demonstration of *in situ* bioremediation to treat groundwater contaminated with VOCs

Cleanup Type:
Field demonstration

Contaminants:
VOCs
- TCE, PCE, 1,2-DCE
- Two mile long TCE plume; TCE concentration ranged from 100 mg/L at source zone to 5 ug/L at distal end of plume
- Source area (DNAPL) - about 200 ft in diameter

Waste Source:
Injection of liquid wastes into the aquifer

Technical:
Lance Peterson
Technical Manager
Northwind Environmental, Inc
Telephone: (208) 528-8718

DOE Contract:
Jim Wright
DOE EM50, Subsurface Contaminants Focus Area
Telephone: (803) 725-5608

Technology:
In Situ Bioremediation
- Sodium lactate (electron donor) injection, extraction, above ground air stripping, and reinjection
- Weekly sodium lactate injections from January to September 1999; no lactate injections from September 2000 to February 2000 because electron donor had accumulated in the aquifer; March 2000 on, bi-monthly injections performed
- 492 ft-long treatment cell created by one injection well and one extraction well; extraction well operated continuously at an extraction rate of 190 L/min

Type/Quantity of Media Treated:
Groundwater
- TCE plume located in a fractured basalt aquifer, 200 to 200 ft bgs
- Unconfined aquifer; groundwater flow - 0.35 to 0.79 ft/day

Regulatory Requirements/Cleanup Goals:
No specific cleanup levels identified for the demonstration

Results:
- After one year of operation, TCE levels were to non-detectable levels in a number of wells, including the original injection well and the three monitoring wells where TCE concentrations were the highest
- Monitoring data indicate that TCE is being degraded by natural attenuation

Costs:
Estimated net present value of implementing ISB at TAN for 15 years - $35,410,000, including $3,750,000 in capital cost, $31,508,000 in O&M cost and $152,000 in D&D cost

Enhanced In Situ Bioremediation at Idaho National Engineering and Environmental Laboratory, Test Area North, Idaho Falls, Idaho (continued)

Description:
At the Test Area North (TAN) at INEEL, liquid wastes containing solvents and radionuclides were injected into an aquifer between 1953 and 1972, resulting in groundwater contamination at the site. TCE, PCE, and 1,2-DCE and radionuclides are present in the groundwater, and the contaminant plume is about two-miles ling and 200 to 450 ft deep.

In 1999, a demonstration of ISB was initiated at the TAN site to treat the source area of the contaminant plume and the more dilute dissolved plume with natural attenuation. Sodium lactate was injected into the subsurface using one injection well and extracted using one well located downgradient of the source to create a treatment cell about 492 ft long. After a one-year period, TCE concentrations in a number of wells were reduced to non-detectable levels and evidence of natural attenuation was observed in the dissolved plume. The system was continuing to operate through 2001. According to DOE, the technical applicability of ISB is dependent upon site geology, concentrations of native nutrients, and the natural oxidation potential of the subsurface.

Enhanced *In Situ* Bioremediation Process at the ITT Roanoke Site, Roanoke, VA

Site Name:
ITT Industries Night Vision (ITTNV) Division Plant

Location:
Roanoke, VA

Period of Operation:
March 1998 - July 1999

Cleanup Authority:
RCRA

EPA Contact:
Mr. Vince Gallardo, Project Manager
U.S. EPA
National Risk Management Research Laboratory (NRMRL)
26 West Martin Luther King Drive
Cincinnati, OH 45268
Phone: (513) 569-7176
Fax:: (513) 569-7620
E-mail: gellardo.vincente@epa.gov

Purpose/Significance of Application:
Field demonstration of the enhanced *in situ* bioremediation process for chlorinated organics in groundwater in fractured bedrock

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated and Non-Chlorinated Organic Compounds
- Chloroethane - 330 µg/L; 1,1 DCA - 960 µg/L; cis-1,2-DCE - 3,100 µg/L; vinyl chloride - 1,100 µg/L

Waste Source:
Manufacturing of equipment, leaking underground storage tanks containing chlorinated and non-chlorinated compounds used as cleaning solvents

Type/Quantity of Media Treated:
Groundwater

Technology:
In situ bioremediation
- Injection well delivers a mixture of air, nitrous oxide, triethyl phosphate, and methane at 15-30 psi and 20 scfm. The composition of the mixture was not specified.
- Groundwater and soil vapor monitoring wells were installed upgradient, down-gradient, and cross-gradient relative to the injection well location to delineate the zone of influence and monitor contaminant levels.

Regulatory Requirements/Cleanup Goals:
- 75% reduction (with a 0.1 level of significance) in the groundwater concentration of chloroethane, DCA, DCE, and vinyl chloride within 6 months within the zone of influence

Results:
- After 16 months of operation, treatment goals were achieved for cis-1,2-DCE and VC

Costs:
- No information about costs was provided

Description:
The ITTNV plant in Roanoke, VA is an active manufacturing plant that produces night vision devices and related products. Groundwater contamination resulted from tank leaks of chlorinated and nonchlorinated compounds used as manufacturing cleaning solvents. The contaminated area included groundwater in fractured bedrock.

Of the four contaminants analyzed, two (cis-1,2-DCE and VC) met the treatment goal of 75% reduction (with a 0.1 level of significance) in the zone of influence. The demonstration was originally intended to last 6 months, but process optimization and modifications resulted in extending the evaluation period to 16 months.

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In Situ Bioremediation Using Hydrogen Release Compound® or Molasses at Six Drycleaner Sites, Various Locations

Site Name:
Contemporary Cleaners; Decorah Shopping Center Drycleaners; Dixie Cleaners; Hayden Island Cleaners; Springdale Cleaners; Washington Square Mall Dry Cleaners

Location:
Contemporary Cleaners, FL; Decorah Shopping Center Drycleaners, WI; Dixie Cleaners, FL; Hayden Island Cleaners, OR; Springdale Cleaners, OR; Washington Square Mall Dry Cleaners, WI

Period of Operation:
Contemporary Cleaners - 154 days, dates not specified
Decorah Shopping Center Drycleaners - not specified
Dixie Cleaners - June, 2000 to June, 2001
Hayden Island Cleaners - 15 months, dates not specified
Springdale Cleaners - not specified
Washington Square Mall Dry Cleaners - 20 months, dates not specified

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 or TCE
- Concentrations varied by site ranging from 0.025 to 1,230 mg/L for PCE and 0.00039 to 8.3 mg/L for TCE
- Two sites reported that DNAPLs were present

Waste Source:
Waste and wastewater from drycleaning operations

Contacts:
Varied by site

Technology:
In Situ Bioremediation
- Injection of hydrogen release compound was performed at 4 sites at depths from 12 to 40 feet. Treatment areas ranged from 200 to 14,600 square feet and total HRC® injected ranged from 2,300 to 22,000 pounds of HRC®. Injection wells were installed using direct push techniques, usually in a grid based on 10-foot centers. HRC® was applied in a single injection.
- Injection of molasses was performed at one site at depths from 12 to 17 feet. The treatment area was not specified. Injection wells were installed using direct push techniques. Six injections were performed over a period of 6 months, with 15-25 gallons of molasses and 25 gallons of water injected during each injection.

Type/Quantity of Media Treated:
Groundwater
- Groundwater conditions varied by site
- Plume sizes ranged from 15,000 to 140,000 square feet; treatment areas ranged from 200 to 18,000 square feet.

Regulatory Requirements/Cleanup Goals:
- Cleanup goals were based on state regulatory goals or EPA MCLs.
- Specified cleanup goals included 0.003 mg/L for PCE and 0.003 to 0.005 mg/L for TCE

In Situ Bioremediation Using Hydrogen Release Compound® or Molasses at Six Drycleaner Sites, Various Locations (continued)

Results:
In situ bioremediation with HRC® (5 sites):
- All of the sites reported reductions in PCE and TCE, and evidence of biodegradation, including increases in the concentrations of PCE and TCE degradation products
- Information about progress towards specific cleanup goals was not provided

In situ bioremediation with molasses (1 site):
- Sampling results from a 20-month period following bioremediation indicated that PCE was reduced from 2 mg/L to below analytical detection limits (detection limits were not specified). TCE concentrations were reduced from 0.9 to 0.015 mg/L

Costs:
- Total project costs ranged from $79,000 to treat a 200 square foot area to depths from 25 to 40 feet; to $300,000 to treat an 18,400 square foot area to from 25 to 30 feet
- Costs included well installation, application of the technology, and post-treatment monitoring but do not include site assessment

Description:
In situ bioremediation was conducted at six 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 1,230 mg/L and TCE in groundwater as high as 8.3 mg/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 HRC® at five sites and molasses at one site. The injection wells were installed using direct push techniques, and the concentrations of TCE and PCE were monitored after the application of the technology. A single injection of HRC® was performed at the five sites. Reductions in PCE and TCE concentrations and increases in PCE and TCE biodegradation products were reported for all five sites. At one site, molasses was injected 6 times over a period of 20 months. PCE concentrations in groundwater decreased to below analytical detection limits and the site was closed.

Surfactant-Enhanced DNAPL Flushing at Marine Corps Base Camp Lejeune, Site 88, Building 25, NC

Site Name:
Marine Corps Base Camp Lejeune, Site 88, Building 25

Location:
Camp Lejeune, NC

Period of Operation:
April - August 1999

Cleanup Authority:
Not identified

EPA Contact:
Gena Townsend, EPA Region IV
Phone: (404) 562-8538
E-mail: townsend.gena@epamail.epa.gov

Purpose/Significance of Application:
Field demonstration of Surfactant-Enhanced Aquifer Flushing (SEAR) surfactant flushing technology for treating PCE and DNAPL in groundwater

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated Solvents and Total Petroleum Hydrocarbons (TPH)
- PCE concentrations in groundwater as high as 54 mg/L
- PCE present as DNAPL and Varsol™, a petroleum distillate, is present as LNAPL in groundwater

Waste Source:
Operation of central dry cleaning facility

ESTCP Project Manager:
S. Luara Yeh, P.E.
Naval Facilities Engineering Service Center
Phone: (805) 982-1660
E-mail: yehsl@nfesc.navy.mil

Demonstration Contact:
Dr. Leland Vane, Pervaporation Team Leader
U.S. EPA National Risk Management Research Laboratory
Phone: (513) 569-7799
E-mail: vane.leland@epamail.epa.gov

Technology:
In Situ Soil Flushing - SEAR
- Test area was 20 feet wide by 30 feet long and 20 feet deep
- Solution consisted of a surfactant, calcium chloride, isopropyl alcohol, and water was injected through 3 injection wells at a rate of 0.133 gallons per minute (gpm) per well for 58 days; six extraction wells removed subsurface liquids at a combined rate of 1 gpm
- Above-ground treatment included gravity separation to remove separate phase DNAPLs, pervaporation to remove dissolved-phase contaminants, and ultrafiltration (UF) to reconcentrate surfactant fluid prior to reinjection
- Surfactant flush was followed by a 74 day water flush to remove injected chemicals and solubilized or mobilized contaminants
- Partitioning interwell tracer test (PITT) to demonstrate DNAPL removal and recovery of injected solution

Type/Quantity of Media Treated:
Groundwater
- Shallow surficial aquifer at a depth of 16 to 20 ft; differences in permeability between the shallower, more permeable zone (hydraulic conductivity of 10^{-4} cm/sec) and the basal low permeability zone ((hydraulic conductivity of 10^{-5} cm/sec)
- Majority of DNAPL is present in a low permeability silty layer at base of the shallow aquifer; 105 gallons of DNAPL estimated to be present in the test zone

Regulatory Requirements/Cleanup Goals:
Performance objectives established for the demonstration included:
- 96% DNAPL removal efficiency for groundwater remediation
- Remove 95% of extracted contaminant mass with above-ground treatment
- 90% recovery of injected surfactant, isopropyl alcohol, and tracer

Surfactant-Enhanced DNAPL Flushing at Marine Corps Base Camp Lejeune, Site 88, Building 25, NC (continued)

Results:

- A total of 76 gal of PCE were recovered during the demonstration with 32 gal recovered as solubilized DNAPL and 44 gal as free-phase DNAPL
- DNAPL was effectively removed from the more permeable layer (above 17.5 ft bgs) with DNAPL remaining in the lower permeability basal silt layer; DNAPL recovery in more permeable layer -at a rate of 92%-96%; DNAPL recovery from entire test zone (both layers) - 72%; the poor sweep of the surfactants across the lower portion of the contaminated zone was attributed primarily to the permeability contracts between the two zones
- Above-ground treatment system removed > 95% of extracted PCE; surfactant recovery - 77%; injected isopropyl alcohol recovery - 88%

Costs:

- Total demonstration costs were $3.1 million, including DNAPL source zone characterization, surfactant selection, well field installation, free-phase DNAPL removal equipment, pre-treatment PITT, application of the technology, surfactant regeneration, and indirect costs
- Estimated total costs for full-scale systems were estimated at $1.5 million to treat a 2,500 square foot area, $6.8 million to treat a 0.5 acre area, and $12.8 million to treat a 1 acre area.

Description:

Marine Corps Base Camp Lejeune, Site 88, Building 25 is the location of a central dry cleaning facility. The site is contaminated with PCE and Varsol™, a petroleum distillate from storage and use during drycleaning operations. PCE is present in groundwater at the site as DNAPL. Varsol™ is present as LNAPL. A demonstration of the surfactant-enhanced aquifer remediation system (SEAR) was performed by the U.S. Department of Defense Environmental Security Technology Certification Program (ESTCP), targeted at treating DNAPL in groundwater.

Injection of a solution of surfactant, isopropyl alcohol, and calcium chloride was conducted for 58 days, followed by a 78-day water flushing to remove mobilized contaminants and residual flushing solution. DNAPL was effectively removed from the more permeable layer (above 17.5 ft bgs) with DNAPL remaining in the lower permeability basal silt layer. The results of the demonstration showed that aquifer heterogeneity has a strong influence on the performance of SEAR and the sensitivity of the technology to permeability contrasts indicated the importance of performing a thorough DNAPL source zone characterization.

In Situ Treatment Using Cosolvent Flushing, Thermal Desorption, or In-Well Air Stripping at Four Drycleaner Sites

Site Name:
Camp Lejeune Marine Corps Base, Building 25; Cedarburg Drycleaners; Former Nu Look One Hour Cleaners; Former Sages Drycleaners

Location:
Marine Corps Base Camp Lejeune, Building 25, NC; Cedarburg Drycleaners, Cedarburg, WI; Former Nu Look One Hour Cleaners, Coral Springs, FL; Former Sages Drycleaners, Jacksonville, FL

Period of Operation:
Camp Lejeune Marine Corps Base, Building 25 - March 15 - August 15, 1999
Cedarburg Drycleaners - Not specified
Former Nu Look One Hour Cleaners - 30 days (specific dates not specified)
Former Sages Drycleaners - Not specified

Cleanup Authority:
Cedarburg Drycleaners - State cleanup; all others not specified

Purpose/Significance of Application:
Field demonstrations of *in situ* technologies for the remediation of chlorinated solvents in soil and groundwater at drycleaner facilities

Cleanup Type:
Field demonstrations

Contaminants:
Chlorinated Solvents:
- All of the sites were contaminated with PCE and TCE
- Concentrations in groundwater varied by site ranging from 1.9 to 170 mg/L for PCE and 0.8 to 34 mg/L for TCE.
- One site (Cedarburg Drycleaners) also reported soil contamination with PCE (highest concentration 21 mg/kg) and TCE (highest concentration 0.3 mg/kg).

Waste Source:
Waste and wastewater from drycleaning operations

Contacts:
Varied by site

Technology:
Cosolvent flushing
- Cosolvent flushing was tested at Building 25, Camp Lejeune Marine Corps Base and Former Sages Drycleaners.
- At the Building 25, Camp Lejeune Marine Corps Base site, treatment consisted of injecting 9,718 lb of a custom surfactant (Alfoterra 145-4-PO sulfate™), 38,637 lb isopropanol and 427 lb calcium chloride. Extraction wells recovered the injected solution and groundwater, and 19% (1,800 lb) of the total surfactant injected was recycled.
- At the Former Sages Drycleaner site, treatment consisted of injecting 9,000 gallons of a 95% ethanol and 5% water mixture through 3 injection wells. Injected fluids and groundwater were recovered through 6 extraction wells. Cosolvent fluid was injected at a rate of 4 gpm. The extraction rate was 8 gpm. The extracted mixture of PCE, ethanol, and water was treated with the Akzo Nobel Macro Porous Polymer (MPP) system for removal of PCE. Approximately 160,000 gallons of an ethanol and water mixture was disposed of off-site.

Thermally enhanced SVE
- At the Cedarburg Drycleaners site, *in situ* thermal desorption was used to treat contaminated soil. The treatment process used a chain trencher to break up and pulverize the soil matrix while hot air at temperatures up to 700˚F was forced into the trench. Vapors from the process were collected using a vacuum hood. In addition, groundwater was treated at this site using bioremediation, which was performed by injecting a dilute molasses solution to enhance microbial activity that would result in a reductive dechlorination of chlorinated contaminants.

In-well air stripping
- At the Former Nu Look One Hour Cleaners site, a single pilot recirculating well using in-well airlift through a 12-ft stripping column was operated for a period of 30 days. Air was introduced through a diffuser at an average rate of 35 cfm. and 5 psig. The vapor stream extracted from the wellhead was recycled through a carbon treatment system and reused in the airlift stripping column. This minimized the injection of oxygen into the well, which helped maintain an anaerobic subsurface environment.

In Situ Treatment Using Cosolvent Flushing, Thermally Desorption, or In-Well Air Stripping at Four Drycleaner Sites (continued)

Type/Quantity of Media Treated:
- Groundwater plume areas ranged from 0.27 to 17 acres. The deepest reported plume went to 92 feet below ground surface. Actual treatment areas ranged from 6,000 to 150,000 cubic feet for groundwater treatments. At the Cedarburg Drycleaners site, the 100 cubic feet of soil were treated.

Regulatory Requirements/Cleanup Goals:
The Cedarburg Drycleaners site reported a cleanup goal of less than 6 mg/kg PCE in soil based on state requirements. Cleanup goals for the other sites were not reported.

Results:
- At the Building 25, Camp Lejeune Marine Corps Base site, 72% (74 - 88 gallons) of the DNAPL in the treatment zone were removed. However, DNAPL was not removed from low permeability areas of the treatment zone. Test results indicated that the technology is not effective for soils with a permeability of less than 1.4 feet per day.
- At the Cedarburg Drycleaners site, soil PCE concentrations were reduced to below 0.4 mg/kg. However, treatment was limited because the unit used could not penetrate deep enough to reach all contamination.
- At the Former Nu Look One Hour Cleaners site, a 75% reduction in volatile organic compounds was achieved in a 62-foot radius around the in-well air stripping unit. Slight rebounds of PCE were observed 6 months after completion of the demonstration.
- At the Former Sages Drycleaners site, 63% (11 gallons) of the DNAPL in the treatment zone were removed. Residual ethanol remaining after the flushing process reportedly enhanced biodegradation of chlorinated compounds.

Costs:
Reported costs:
- Building 25, Camp Lejeune Marine Corps Base - Not reported
- Cedarburg Drycleaners design and implementation costs - $48,000 for soil treatment, $44,000 for groundwater treatment
- Former Nu Look One Hour Cleaners total costs- $193,000
- Former Sages Drycleaners design and implementation costs - $440,000

Description:
Field demonstrations of *in situ* treatment technologies were conducted at four drycleaner sites drycleaner sites contaminated with TCE and PCE as the primary contaminants. The technologies demonstrated included cosolvent flushing (2 sites), thermal desorption, and in-well air stripping. The Cedarburg Drycleaners site reported a cleanup goal of less than 6 mg/kg PCE in soil based on state requirements. Cleanup goals for the other sites were not reported.

Well Injection Depth Extraction (WIDE) Soil and Groundwater Flushing at RMI Titanium Plant, Ashtabula, Ohio

Site Name:	Location:
Site Name: RMI Titanium Plant, Ashtabula Environmental Management Project (AEMP)	**Location:** Ashtabula, OH
Period of Operation: January, 1999 - August 1999	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Field demonstration of hybrid soil and groundwater flushing/soil vapor extraction treatment of trichloroethylene (DNAPL) in clay soil	**Cleanup Type:** Field demonstration
Contaminants: Trichloroethylene (TCE) • TCE concentrations up to 632 mg/L in the groundwater Uranium (U) • U concentrations up to 13 mg/L in the groundwater	**Waste Source:** Uranium metals processing

Technical Contact:
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Project Manager
National Energy Technology Laboratory (NETL)
Phone: (304) 286-4412
E-mail: kfrohn@NETL.doe.gov

Technology:
Soil and groundwater flushing - Well Injection Depth Extraction (WIDE)
- WIDE system is a hybrid soil flushing/soil gas extraction system that uses prefabricated vertical wells (PVWs) for *in situ* remediation of low permeability soils
- Demonstration area - 70 feet by 70 feet
- WIDE system used a grid of over 480 PVWs installed to a depth of 15 feet; the above-ground treatment system to treat TCE-contaminated groundwater was granular activated carbon followed by discharge to an on-site wastewater treatment plant. Extracted soil gas was also treated using granular activated carbon followed by release to the atmosphere .
- Demonstration was conducted in extraction only mode, and extraction/injection mode. During extraction only test, the groundwater extraction rate ranged from 25 to 150 gallons per hour and the soil gas extraction rate ranged from 120 to 350 standard cubic feet per minute. The system was operated in extraction only mode for 6 hours per day over a period of 23 days. During extraction/injection test, 120 gallons per hour of water were injected and an equal amount extracted over a 50 hour period. Information is not available for the air extraction rate in the extraction/injection test.

Type/Quantity of Media Treated:
Soil:
- The treatment remediated a 70 foot by 70 foot area from the surface to a depth of 15 feet. The groundwater table ranged from 2 to 3 feet bgs before the demonstration.

Groundwater:
- During extraction only test, the groundwater extraction rate ranged from 25 to 150 gallons per hour. During extraction/injection test, 120 gallons per hour of water were injected and an equal amount extracted.

Regulatory Requirements/Cleanup Goals:
- TCE: <0.005 mg/L in groundwater
- Design, construct, operate, and monitor the performance of the WIDE system

Well Injection Depth Extraction (WIDE) Soil and Groundwater Flushing at RMI Titanium Plant, Ashtabula, Ohio (continued)

Results:
- Groundwater monitoring data over eight months following demonstration indicated TCE concentration reductions ranged from 46% to 57%.
- The TCE and U extraction rates (including contaminants extracted from both groundwater and soil vapor) for the extraction only test were 2,800 mg/hour and 420 mg/hour respectively.
- The TCE and U extraction rates (including contaminants extracted from both groundwater and soil vapor) for the extraction/injection test were 1,300 mg/hour and 640 mg/hour respectively.

Costs:
- The demonstration program had a capital cost of $386,000 and estimated annual O&M cost (the demonstration was performed in 8 months) of $200,000.
- The estimated costs of treating the entire 1.25 acre TCE groundwater plume were $1.3 million capital cost and $0.2 million annual cost over a treatment time of 5 years to meet the <0.005 mg/L cleanup goal for TCE.

Description:
The RMI Titanium Plant is a former uranium processing facility which supplied extruded an milled uranium products for use within DOE's weapons complex. A former evaporation pond is responsible for the TCE and U contamination of groundwater at the site. DOE's Office of Science and Technology, in coordination with AEMP, conducted a demonstration of soil flushing at this site.

The soil and groundwater flushing system was tested in several modes of operation over a period of eight months on a 70 foot by 70 foot area covering the former evaporation pond. The technology was tested in extraction only and extraction/injection mode. Eight months after the test, TCE concentrations in the groundwater were reduced from 46% to 57%.

In-Well Vapor Stripping Technology at Brookhaven National Laboratory, Upton, New York

Site Name:
Brookhaven National Laboratory

Location:
Upton, New York

Period of Operation:
September 29, 1999 to ongoing (data available through March 2001)

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Demonstration of UVB recirculating well technology to treat groundwater contaminated with VOCs

Cleanup Type:
Field demonstration

Contaminants:
VOCs
- Carbon tetrachloride, PCE, TCE, DCE, TCA
- Maximum well influent concentrations (ug/L) - carbon tetrachloride (1540), PCE (330), total VOC (1900)

Waste Source:
Discharges from operations at the site and leaking underground storage tanks

DOE Contacts:
James Wright
DOE-SR, Subsurface Contaminants Focus Area
Telephone: (803) 725-5608

Vinnie Racaneillo
Brookhaven National Laboratory
Upton, NY
Telephone: (631) 344-5436

Vendor Contact:
Eric Klingel
IEG-Technologies Corporation
Telephone: (704) 660-1673
E-mail: eklingel@juno.com

Technology:
In-Well Vapor Stripping (IWVS); demonstration of UVB system
- 7 UVB wells installed in Upper Glacial Aquifer perpendicular to the VOC plume
- Each well - 8-inch diameter steel casing and two 20-ft long stainless steel screed separated by 25-35 ft of casing and inflatable packer material; equipped with an air stripping tray
- Wells installed to depths between 193 and 243 ft below grade
- Extraction rate - 60 - 75 gpm per well; system average - 420 gpm
- Average air flow rate for each well - 425 to 791 cfm
- 34 monitoring wells screened in the Upper Glacial Aquifer

Type/Quantity of Media Treated:
Groundwater; Upper Glacial Aquifer
- Hydraulic conductivity - 634-1,115 gpd/ft^2
- Groundwater flow direction - south
- Average horizontal groundwater velocity - 0.73 ft/day
- 278 million gallons of groundwater treated as of March 2001

Regulatory Requirements/Cleanup Goals:
Not specified for the demonstration

Results:
- Results reported through March 2001
- Average removal efficiencies for total VOCs ranged from 88.06% to 96.5% with an average system efficiency of 92.82%
- 278 million gallons of groundwater treated and 300 pounds of total VOCs removed
- Influent and effluent concentrations from the 7 wells have decreased since system startup
- Within the zone of influence of the recirculation cell, groundwater rate estimates for the system using field data range from 50% to 75%

Costs:
Estimated cost savings for the UVB system compared to a pump and treat system is $161,000 based on a discounted cash flow analysis

In-Well Vapor Stripping Technology at Brookhaven National Laboratory, Upton, New York (continued)

Description:
At the DOE Brookhaven National Laboratory (BNL) in Upton, New York, groundwater is contaminated by various chlorinated organic compounds to depth ranging from 150 to 230 ft below surface. BNL is situated over a sole-source aquifer and was placed on the National Priorities List in 1989. DOE is remediating the site under a Federal Facilities Agreement, including OU 111, a groundwater plume originating near the south central portion of the site and extending beyond the sites boundaries. The groundwater plume is located within a complex glacial aquifer.

In September 1999, DOE began a demonstration of in-well vapor stripping technology at OU 111 using the patented UVB system from IEG-Technologies Corporation. Seven UVB wells, each equipped with an air stripper, were installed along the plume. As of March 2001, 300 pounds of VOCs have been removed and more that 278 million gallons of groundwater have been treated. The system is continuing to operate. According to DOE, the technical applicability of in well vapor stripping is dependent upon the hydrogeological properties of the saturated and unsaturated zones, the geochemistry of the aquifer, and the contaminants at the site.

Recirculating Well Technologies at the Massachusetts Military Reservation, CS-10 Plume

Site Name: Massachusetts Military Reservation, CS-10 Plume		**Location:** Cape Cod, Massachusetts
Period of Operation: Pilot testing - December 21, 1996 - May 1997 Continued operation of pilot systems through May 4, 1999	**Cleanup Authority:** Federal Facilities Agreement 1991	**EPA Contact:** Michael Jasinski U.S. EPA Region 1 One Congress Street, Suite 1100 Boston, MA 02114 Phone: (617) 918-1352 E-mail: jasinski.mike@epa.gov
Purpose/Significance of Application: Field demonstration of two recirculating well technologies to treat chlorinated solvents in groundwater		**Cleanup Type:** Field demonstration
Contaminants: Chlorinated Solvents • TCE - 3,200 ug/L, PCE - 500 ug/L, and 1,2-DCE - 58 ug/L		**Waste Source:** Fuel spills and leaks from engine maintenance operations and underground storage tanks
Jim Snyder HQ AFCEE/MMR 322 E. Inner Road, Box 41 Otis ANGB, MA 02542-5028 Phone: (508) 968-4670 Spence Smith HQ AFCEE/MMR 322 E. Inner Road, Box 41 Otis ANGB, MA 02542-5028 Phone: (508) 968-4670, Ext 5603 E-mail: Spence.Smith@MMR.brooks.af.mil	**Technology:** UVB recirculating wells (with air stripping) • UVB uses an in-well stripping platform, operated under negative pressure, with a four-screen design • Two UVB wells were used; pumps operated at 39 to 61 gpm; the air stripping unit used an air to water ratio ranging from 120:1 to 150:1 • Air treatment consisted of GAC NoVOCs recirculating wells (with air stripping) • NoVOCs uses a double-cased, in-well vapor-stripping system; pressurized air-lift pumping is used to extract water through screens located at the base of the plume; VOCs are stripped and filtered through GAC; treated water is reinjected • Two NoVOCs wells were used; pumps operated at 160 gpm for one well and 140 gpm for the other • 24 monitoring wells (8 clusters of 3 each) were used to monitor the groundwater at each test site **Type/Quantity of Media Treated:** Groundwater • Plume extended approximately 12,500 feet downgradient from the source area, with a width of up to 3,600 feet • Three hydrostratigraphic zones were identified beneath the test sites - upper, middle, and lower • UVB pilot test treated 23 million gallons; quantity treated not specified for NoVOCs pilot test	
Regulatory Requirements/Cleanup Goals: • The pilot tests were conducted to assess the overall feasibility of using recirculating well technology to achieve “significant contaminant reduction” (not further quantified) • A performance standard was established as 1 ug/L for TCE in the discharge from the air stripper, with TCE used as a measure of total VOCs in the water		

Recirculating Well Technologies at the Massachusetts Military Reservation, CS-10 Plume (continued)

Results:

- The cumulative mass of TCE removed by the UVB wells during the pilot test was about 18 kg; TCE concentrations in the groundwater were reduced in the upper and lower hydrostratigraphic zones, and remained relatively stable in the middle zone
- The cumulative mass of TCE removed by the NoVOCs wells during the pilot test was about 43 kg; TCE concentrations in the groundwater remained stable
- The pilot study and continued operation indicated that recirculating well technology reduced concentrations of TCE, PCE, and 1,2-DCE; however, a comparison of the two technologies in terms of contaminant reduction could not be made from the available data for several reasons

Costs:

- The actual cost for the CS-10 recirculating well pilot test and subsequent operational period was approximately $3,000,000, consisting primarily of costs for drilling ($1,583,000) sampling ($635,000), and construction ($554,000).
- Information was not provided about the projected cost for a full-scale treatment system.

Description:

MMR is a military training facility located in the upper western portion of Cape Cod, Massachusetts, about 60 miles southeast of Boston. Leaks and spills from historical operations including vehicle maintenance and repair, parts cleaning, and painting; storage of petroleum products and hazardous materials; and disposal of wastes in landfills resulted in soil and groundwater contamination. A Technical Review and Evaluation Team recommended that pilot-scale testing of recirculating well technology be performed in the southeastern area of the CS-10 plume within the industrial area to evaluate the effectiveness of this innovative technology for reducing concentrations of contaminants in the groundwater. The pilot testing was performed prior to installation of a groundwater extraction system, identified as the interim remedy for CS-10 groundwater the ROD signed in September 1995.

During the pilot test, the cumulative mass of TCE removed by the UVB wells was about 18 kg and about 43 kg for the NoVOCs system. According to the prime contractor at the site, the results of the pilot tests indicate that recirculating well system hydraulics are more sensitive to site-specific hydrogeologic conditions than extraction, treatment, and reinjection. In addition, modeling results indicated that the presence of low hydraulic conductivity layers can inhibit the establishment of effective recirculation wells.

In-Well Air Stripping at Naval Air Station, North Island, San Diego, CA

Site Name:
Installation Restoration Site 9, Naval Air Station (NAS) North Island

Location:
San Diego, CA

Period of Operation:
February 1998 - January1999

Cleanup Authority:
CERCLA

EPA Contact:
Ms. Michelle Simon
U.S. EPA
26 W. Martin Luther King Drive
Cincinnati, OH 45268
Phone: (513) 569-7469
Fax:: (513) 569-7676
E-mail: simon.michelle@epa.gov

Purpose/Significance of Application:
Field demonstration of in-well air stripping to treat groundwater contaminated with high levels of VOCs

Cleanup Type:
Field demonstration

Contaminants:
Chlorinated VOCs
- 1,1 DCE - 3,530 µg/L, cis-1,2-DCE - 45,000 µg/L, TCE - 1,650 µg/L

Waste Source:
Wastes from various operations at the base

Technology Contact:
Joe Aiken
MACTEC, Inc.
1819 Denver West Drive, Suite 400
Golden, CO 80401
Phone: (303) 278-3100
Fax: (303) 278-5000

Technology:
In-well air stripping
- The system consisted of a single well casing installed into the contaminated saturated zone, with two screened intervals below the groundwater table, and an air injection line extending into the groundwater within the well. The stripped VOC vapors were removed by a vacuum applied to the upper well casing and treated using a flameless oxidation process.
- The recharge screen was located in the saturated zone, rather than the usual location in the vadose zone, because of the presence of a hydraulic barrier between the vadose zone and the intake screen, which could adversely affect the groundwater circulation through the system.
- Effluent air flow rate from the well ranged from 50 to 69 scfm.

Type/Quantity of Media Treated:
Groundwater

Regulatory Requirements/Cleanup Goals:
- Objectives of demonstration included assessing the technology's ability to treat groundwater contaminated with high levels of chlorinated VOCs

Results:
- Total estimated VOC removed during demonstration - 92.5 pounds; average total VOC mass removed ranged from 0.01 to 0.14 pounds per hour
- The mean concentrations of contaminants in the treated water discharged from the system: 1,1 DCE - 27 µg/L, cis-1,2-DCE - 1,400 µg/L, and TCE - 32 µg/L
- Measurable pressure changes occurred at crossgradient locations 30 feet from the well
- Fouling from iron precipitation and biological growth occurred, reducing pumping rates significantly. Iron precipitation was reduced by adding citric acid, but biological fouling was not successfully controlled.

Costs:
- Projected capital costs for a full-scale single system - $190,000; projected annual O&M costs - $160,000 the first year, and $150,000 per year thereafter

In-Well Air Stripping at Naval Air Station, North Island, San Diego, CA (continued)

Description:
A demonstration of in-well air stripping was performed at the NAS North Island, Installation Restoration Site 9 to assess the technology's ability to treat groundwater contaminated with high levels of chlorinated VOCs. The project was conducted under EPA's Superfund Innovative Technology Evaluation (SITE) program in conjunction with EPA's Technology innovation office, Naval Facilities Engineering Command Southwest Division (SWDIV), Navy Environmental Leadership Program, and Clean Sites, Inc.

During the demonstration, in-well air stripping removed an estimated 92.5 pounds of VOCs. The remediation at this site was challenging because the groundwater contained total dissolved solids (TDS) concentrations ranging from 18,000 to 41,000 mg/L, which are higher than those typically found in drinking water aquifers. Operational difficulties associated with biofouling and the precipitation of iron resulted in an incomplete evaluation of the technology.

Permeable Reactive Barriers (PRBs) Interim Summary Report: PRBs Using Continuous Walls to Treat Chlorinated Solvents

Site Name:
Six Sites- Copenhagen Freight Yard/ Copenhagen, Denmark; Former Manufacturing Site/ Fairfield, New Jersey; Industrial Site/ Manning, South Carolina; Kansas City Plant/ Kansas City, Missouri; Shaw Air Force Base (AFB)/ Sumter, South Carolina; Borden Aquifer/ Ontario Canada

Location:
Various locations

Period of Operation:
Installation dates ranging from 1991 (Borden Aquifer) -1998 (Copenhagen Freight Yard)

Cleanup Authority:
CERCLA, RCRA, and other regulatory programs (varied by site)

Purpose/Significance of Application:
Use of PRBs with a continuous wall configuration to treat groundwater contaminated primarily with chlorinated solvents

Cleanup Type:
Full scale and field demonstrations

Contaminants:
Chlorinated Solvents
- PCE, TCE, DCE, DCA, VC
- The maximum influent concentration for chlorinated solvents was 250,000 µg/L for TCE

Waste Source:
Varied by site

Contacts:
Varied by site

Technology:
Permeable Reactive Barriers using a continuous wall to treat groundwater contaminated with chlorinated solvents:
- Copenhagen Freight Yard- Supported excavation, using iron
- Former Manufacturing Site- Supported excavation, using iron and sand
- Industrial Site- Continuous trench, using iron
- Kansas City Plant- Supported excavation, using iron and sand
- Shaw Air Force Base- Continuous trench, using iron
- Borden Aquifer- Supported excavation, using iron and sand

Type/Quantity of Media Treated:
Groundwater.

Regulatory Requirements/Cleanup Goals:
Regulatory requirements and cleanup goals varied by site, ranging from non-detect levels to 340 µg/L

Results:
All six PRBs profiled in the case study provided some data about project performance; four of the sites (the Copenhagen Freight Yard, the Former Manufacturing Site, the Industrial Site, and the Kansas City Plant) also provided information about goals for project performance. All four of those PRBs met, or were meeting, some or all of their performance goals based on available information. At the six sites, individual contaminant concentrations were reduced to below site-specific cleanup goals ranging from non-detect levels to 340 µg/L.

Costs:
- Installation cost information was available for all the projects included in the report. Total project installation costs ranged from $30,000 for the Borden Aquifer PRB to $1.3 million for the PRB at the Kansas City Plant. The Borden PRB was a pilot-scale project and the installation cost excluded the cost for labor and reactive media, which had been donated. The Kansas City PRB was a full-scale project and was 130 feet long. Design costs ranging from $50,000 for the Industrial Site PRB to $200,000 for the Kansas City PRB were provided for four of the sites.

Permeable Reactive Barriers (PRBs) Interim Summary Report: PRBs Using Continuous Walls to Treat Chlorinated Solvents (continued)

Description:
This report provides an interim summary of information about six projects (five full-scale and one pilot-scale) involving the application of PRB technologies with a continuous wall configuration in the treatment of groundwater contaminated with chlorinated solvents.

Continuous walls have been used to intercept and treat groundwater contaminated with chlorinated solvents without significantly affecting groundwater flow. Lessons learned at the PRB sites summarized in this report include those related to specific successes and issues associated with installing continuous walls under various environmental conditions and factors affecting the PRB performance at specific sites.

Permeable Reactive Barriers (PRBs) Interim Summary Report: PRBs Using Continuous Walls to Treat Metals

Site Name: Five Sites - Haardkrom Site/ Kolding, Denmark; Chalk River Laboratories/ Ontario, Canada; Nickel Rim Mine Site/ Sudbury, Ontario, Canada; Tonolli Superfund Site/ Nesquehoning, Pennsylvania; U.S. Coast Guard Support Center/Elizabeth City, North Carolina	**Location:** Various locations
Period of Operation: Installation dates ranging from 1995 (Nickel Rim Site) - 1999 (Haardkrom Site)Pilot and , varies by site	**Cleanup Authority:** CERCLA, RCRA, and other regulatory programs (varied by site)
Purpose/Significance of Application: Use of PRBs with a continuous wall configuration to treat groundwater contaminated primarily with metals	**Cleanup Type:** Full scale
Contaminants: Chlorinated Solvents, Metals, Inorganics, and Radionuclides • Maximum influent concentrations of 4,320 µg/L for TCE • Metals and inorganics - hexavalent chromium, nickel, iron, sulfite, lead, cadmium, arsenic, zinc, copper • Strontium-90	**Waste Source:** Varied by site

Contacts: Varied by site	**Technology:** Permeable Reactive Barriers using a continuous wall to treat groundwater contaminated with metals: • Haardkrom - Continuous trench, using iron • Chalk River Laboratories - Supported excavation, using clinoptilolite (zeolite) • Nickel Rim Mine - Unsupported excavation, using organic carbon • Tonolli Superfund - Continuous trenching, using limestone • U.S. Coast Guard Support Center - Continuous trenching, using iron
	Type/Quantity of Media Treated: Groundwater

Regulatory Requirements/Cleanup Goals:
Regulatory requirements and cleanup goals vary by site

Results:
Of the five PRBs included in this case study, three (Nickel Rim Mine site, Chalk River Laboratories, and U.S. Coast Guard Support Center) have met or were meeting their performance goals, based on information available at the time of report preparation. At these sites, individual contaminant concentrations were reduced to below site-specific cleanup goals. The Haardkrom site had not met its goals, and the Tonolli Superfund site did not provide performance data.

Installation Costs (excluding design when provided):
Installation cost information was available for four of the five projects in this case study: Haardkrom site $250,000; Chalk River Laboratories $300,000; Nickel Rim Mine Site $30,000; U.S. Coast Guard Support Center $500,000

Description:
This report provides an interim summary of information about five full-scale projects involving the application of continuous wall PRB technologies for the treatment of groundwater contaminated with metals and other inorganic materials. Several different reactive media were used in these applications and results were provided where available.

Continuous walls have been used to intercept and treat groundwater contaminated with metals without significantly affecting groundwater flow. Lessons learned at the PRB sites summarized in this report include those related to specific successes and issues associated with installing continuous walls under various environmental conditions and the suitability of several less common reactive media (organic carbon, limestone, zeolite) for addressing contamination at specific sites.

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Permeable Reactive Barriers (PRBs) Interim Summary Report: PRBs Using a Funnel and Gate Configuration

Site Name:
Fourteen Sites- Aircraft Maintenance Facility/ Southern Oregon; Federal Highway Administration Facility/ Lakewood, Colorado; Former Manufacturing Site/ Seattle, Washington; Industrial Site/ Coffeyville, Kansas; Intersil Semiconductor Site/ Sunnyvale, California; Vapokon Petrochemical Work/ Sonderso, Denmark; Alameda Point/ Alameda, California; Area 5, Dover Air Force Base (AFB)/ Dover, Delaware; Lowry AFB/ Denver, Colorado; Moffett Federal Airfield/ Mountain View, California; Former Mill Site/ Monticello, Utah; East Garrington/ Alberta, Canada; Fry Canyon Site/ Fry Canyon, Utah; Y-12 Site, Oak Ridge National Laboratory/ Oak Ridge, Tennessee

Location:
Various locations

Period of Operation:
Installation dates ranging from 1995 (Intersil and East Garrington) - 2000 (Alameda Point)

Cleanup Authority:
CERCLA, RCRA, and other regulatory programs (varied by site).

Purpose/Significance of Application:
Use of PRBs with a funnel and gate configuration to treat contaminated groundwater.

Cleanup Type:
Full scale and field demonstrations The funnel and gate PRB configuration involves the use of engineered subsurface barriers to capture and route groundwater flow through one or more gates, where treatment occurs. In most cases, funnels have been comprised of sheet piling or slurry cutoff walls. However, engineered preferential groundwater flow pathways employing channels (sometimes referred to as "trench and gate" systems) also have been used to route groundwater flow to a reactive gate.

Contaminants:
Chlorinated Solvents, Other Organics, Metals, Inorganics, Radionuclides
- TCE, PCE, DCE, DCA, vinyl chloride, dichloromethane
- Benzene, toluene, ethylbenzene, xylene, Freon
- Uranium, arsenic, manganese, selenium, vanadium
- Maximum influent concentrations for individual contaminants in each category were 50,000 µg/L (PCE); 60 µg/L (Freon); and 20,700 µg/L (uranium)

Waste Source:
Varied by site

Contacts:
Varied by site

Technology:
Permeable Reactive Barriers using a funnel and gate configuration:
- Aircraft Maintenance Facility- continuous trenching/ supported excavation, iron and sand
- Federal Highway Administration Facility- supported excavation, iron
- Former Manufacturing Site- supported excavation, iron and sand
- Industrial Site- construction method not provided, iron
- Intersil Semiconductor Site- construction method not provided, iron
- Vapokon Petrochemical Work- supported excavation, iron
- Alameda Point- supported excavation, iron and oxygen
- Area 5, Dover Air Force Base (AFB)- supported excavation, iron
- Lowry AFB- supported excavation, iron
- Moffett Federal Airfield- continuous trenching, iron
- Former Mill Site- supported excavation, iron
- East Garrington- supported excavation, oxygen
- Fry Canyon Site- installation method not provided, iron, amorphous ferric oxide, phosphate
- Y-12 Site, Oak Ridge National Laboratory- supported excavation, iron

Type/Quantity of Media Treated:
Groundwater

Regulatory Requirements/Cleanup Goals:
Regulatory requirements and cleanup goals vary by site.

Results:
Performance data was provided for the seven full-scale PRBs included in this report (Aircraft Maintenance Facility, Federal Highway Administration Facility, Former Manufacturing Site, Industrial Site, Intersil Semiconductor Site, Vapokon Petrochemical Work, and Former Mill Site). Five of the seven PRBs with performance data were meeting cleanup goals for chlorinated VOCs and reduced concentrations of individual contaminants from a high of 50,000 µg/L to concentrations below maximum contaminant levels (MCL) or other site-specific cleanup levels.

Costs:
Installation cost information was available for 13 of the 14 projects included in the report. No information concerning PRB operation and maintenance costs was provided for any site. Design costs ranging from $30,000 to $240,000 per site were provided for four of the sites (Former Manufacturing Facility, Vapokon Petrochemical Work, Moffett Federal Airfield, and Fry Canyon Site). The installation cost per site (excluding design costs when provided) ranged from $67,200 for East Garrington to $1 million for the Federal Highway Administration Facility, Intersil Semiconductor, and Y-12 sites.

Description:
This report provides an interim summary of information about fourteen projects (seven full-scale and seven pilot-scale) involving the application of PRB technologies where a funnel and gate configuration was used to treat groundwater contaminated with chlorinated solvents, other organic contaminants, and/or inorganic contaminants. In most cases, funnels have been comprised of sheet piling or slurry cutoff walls. However, engineered preferential groundwater flow pathways employing channels (sometimes referred to as "trench and gate" systems) also have been used to route groundwater flow to a reactive gate under low-permeability aquifer conditions.

Lessons learned at the PRB sites summarized in this report include those related to specific successes and issues associated with installing funnel and gate configurations under various environmental conditions and the suitability of several reactive media for addressing contamination at specific sites.

Permeable Reactive Barriers (PRBs) Interim Summary Report: PRBs Using Injection and Other Emerging Technologies

Site Names and Locations:
Sixteen Sites - Caldwell Trucking/ Northern New Jersey; Former Dry Cleaning Facility/ Westphalia, Germany; Former Industrial Site/ Brunn Am Gebirge, Austria; Arrowhead Associates Former Metal Plating Operation Superfund Site/ Montross, Virginia; Marzone Inc., Chevron Chemical Company/ Tifton, Georgia; Tacony Warehouse/ Philadelphia, Pennsylvania; 100D Area, Hanford Site/Hanford, Washington; Cape Canaveral Air Force Station/ Cape Canaveral, Florida; Launch Complex 34, Cape Canaveral Air Force Station/ Cape Canaveral, Florida; DuPont/ Oakley, California ; DuPont/ Kinston, North Carolina; Industrial Site/ Belfast, Northern Ireland; Massachusetts Military Reservation (MMR) CS-10 Plume/Falmouth, Massachusetts; SAFIRA Test Site/ Bitterfeld, Germany; Savannah River Site TNX Area/ Aiken, South Carolina; X-625 Groundwater Treatment Facility, Portsmouth Gaseous Diffusion Plant/ Piketon, Ohio

Period of Operation:
Installation dates ranging from 1995 (Industrial site) - to 2002 (Arrowhead Associates Former Metal Plating Operation)

Cleanup Authority:
CERCLA, RCRA, and other regulatory programs (varied by site)

Purpose/Significance of Application:
Use of PRBs using injection or other emerging technologies as an installation method to treat contaminated groundwater

Cleanup Type:
Full scale and field demonstrations

Contaminants:
Chlorinated Solvents, BTEX, Pesticides, Freon, Metals, Radionuclides
- TCE, PCE, DCE, DCA, VC, dichloromethane, chlorobenzene, chloroform, and dichlorobenzene
- Maximum influent concentrations for individual contaminants were 390,000 ug/L for TCE; 94,000,000 ug/L for xylenes

Waste Source:
Varied by site

Contacts:
Varied by site

Technology:
Permeable Reactive Barriers using injection and other technologies:

- Caldwell Trucking - Full scale wall, hydraulic fracturing, using iron
- Former Dry Cleaning Facility - Full scale wall, mandrel (H-beam), using iron with iron sponges
- Former Industrial - Full scale reactive vessel, jetting, using activated carbon
- Arrowhead Associates Former Metal Plating Operation - Full scale wall, hydraulic fracturing, using iron
- Marzone Inc./Chevron Chemical Company - Full scale funnel and gate, vibrated I-beam, using activated carbon
- Tacony Warehouse - Full scale reactive vessel, caisson auger, using iron
- 100D Area, Hanford Site - Pilot scale wall, injection, using sodium dithionite
- Cape Canaveral Air Force Station - Pilot scale wall, vibrated I-beam and jetting, using iron
- Launch Complex 34, Cape Canaveral Air Force Station - Pilot scale wall, deep soil mixing, using iron and gravel
- DuPont/ Oakley - Pilot scale wall, hydraulic fracturing, using granular cast iron
- DuPont/ Kinston - Pilot scale wall, hydraulic fracturing, using granular iron
- Industrial Site - Pilot scale reaction vessel, installation method not provided, using iron
- Massachusetts Military Reservation (MMR) CS-10 Plume - Pilot scale wall, hydraulic fracturing, using iron
- SAFIRA Test Site - Pilot scale reaction vessel, large diameter shafts, using hydrogen activation systems
- Savannah River Site TNX Area - Pilot scale reaction vessel, installation method not provided, iron
- X-625 Groundwater Treatment Facility - Pilot scale reaction vessel, horizontal wells, iron

Type/Quantity of Media Treated:
Groundwater

Permeable Reactive Barriers (PRBs) Interim Summary Report: PRBs Using Injection and Other Emerging Technologies (continued)

Regulatory Requirements/Cleanup Goals:
Regulatory requirements and cleanup goals varied by site, ranging from non-detect to 2,130 ug/L.

Results:
Of the six full-scale PRBs, two (Marzone and Tacony) had met or were meeting cleanup goals and one (Caldwell Trucking) had not met it's the cleanup goals. For the remaining three full-scale projects, cleanup goals were not established or performance data not provided. Quantitative information about cleanup goals was not provided for all sites. At the sites that did provide data and were meeting their goals, individual contaminant concentrations were reduced to below site-specific cleanup goals ranging from non-detect to 2,130 ug/L.

Costs:
Cost information was available for 14 of the 16 projects included in the report. Data was provided about installation costs and design costs (for some projects) but not about operation and maintenance costs. For the sites that provided cost data about design, costs ranged from $30,000 to $292,000 per site. The costs to install the PRBs ranged from $130,000 to approximately $5 million per site.

Description:
This report provides an interim summary of information about 16 projects (6 full-scale and 10 pilot-scale) involving the application of PRB technologies where injection or some other type of emerging technology was used for installation. The PRBs installed at these sites used various reactive media for the treatment of groundwater contaminated with chlorinated solvents, other organic contaminants, and/or inorganic contaminants.

Injection and other technologies have been used in the more recent past for several reasons, including avoiding a major disturbance of the subsurface materials, and allowing direct placement of reactive media to the contaminant zones. Lessons learned at the PRB sites summarized in this report include those related to specific successes and issues associated with the emerging technologies employed and their various installation methods and the suitability to specific applications.

Permeable Reactive Barriers (PRBs) Using Iron with a Bulking Agent as a Reactive Media, Various Locations

Site Name:
Eight Sites - F.E. Warren Air Force Base/ Cheyenne, Wyoming; Lake City Army Ammunition Plant/ Independence, Missouri; Seneca Army Depot/ Romulus, New York; Somersworth Sanitary Landfill/ Somersworth, New Hampshire; Watervliet Arsenal/Watervliet, New York; Rocky Flats Environmental Technology, Solar Ponds Plume/ Golden, Colorado; Rocky Flats Environmental Technology, East Trenches Site/ Golden, Colorado; Bodo Canyon/ Durango, Colorado

Location:
Various locations

Period of Operation:
Installation dates ranging from 1995 (Bodo Canyon) to 2000 (Lake City Army Ammunition Plant and Somersworth Sanitary Landfill)

Cleanup Authority:
Varied by site

Purpose/Significance of Application:
Use of PRBs with a reactive media consisting of iron with a bulking agent to treat groundwater contaminated with chlorinated solvents

Cleanup Type:
Full scale and field demonstrations

Contaminants:
Chlorinated Solvents, Carbon Tetrachloride, Chloroform, Methylene Chloride, Metals, Inorganics, and Radionuclides
- Chlorinated solvents including TCE, PCE, DCE, VC
- Maximum influent concentrations for individual contaminants in each category were 21,100 µg/L (TCE) for chlorinated solvents; 4,700 µg/L (total VOCs), and 170,000 µg/L (nitrate) for inorganics.

Waste Source:
Varied by site

Contacts:
Varied by site

Technology:
Permeable Reactive Barriers using iron with a bulking agent:
- F.E. Warren Air Force Base - Full-scale wall, supported excavation, using iron with sand
- Lake City Army Ammunition Plant - Full-scale wall, supported excavation, using iron with sand
- Seneca Army Depot - Full-scale wall, continuous trenching, using iron with sand
- Somersworth Landfill - Full-scale wall, supported excavation, using iron with sand
- Watervliet Arsenal - Full-scale wall, supported excavation, using iron with sand
- Rocky Flats, Solar Ponds - Full-scale reaction vessel, supported excavation, using iron with wood chips
- Rocky Flats, East Trenches - Full-scale reaction vessel, supported excavation, using iron with pea gravel
- Bodo Canyon - Pilot-scale reaction vessel, installation method not provided, iron with copper wool and steel wool

Type/Quantity of Media Treated:
Groundwater

Regulatory Requirements/Cleanup Goals:
Varied by site, ranging from non-detect to 100 µg/L

Results:
Of the seven projects included in this case study, five (F.E. Warren Air Force Base, Somersworth Sanitary Landfill, Watervliet Arsenal, and both Rocky Flats sites) met or were meeting their goals at the time of report preparation. At these sites, individual contaminant concentrations were reduced to below site-specific cleanup goals ranging from non-detect to 100 µg/L. The Seneca Army Depot was not meeting its goals for DCE, and results were not yet available for the Lake City Army Ammunition Plant. The Bodo Canyon site was a pilot study, but results showed contaminants were substantially reduced.

Permeable Reactive Barriers (PRBs) Using Iron with a Bulking Agent as a Reactive Media, Various Locations (continued)

Costs:
Installation cost information was available for four of the eight projects in the case study (F.E. Warren Air Force Base - $2,400,000, Seneca Army Depot - $350,000, Somersworth Sanitary Landfill - $2,000,000, Watervliet Arsenal - $278,000).

Description:
This report provides an interim summary of information about eight projects (seven full-scale and one pilot-scale) involving the application of PRB technologies where iron with a bulking agent was used as a reactive media for the treatment of groundwater contaminated with chlorinated solvents, other organic contaminants, and/or inorganic contaminants.

Lessons learned at the PRB sites summarized in this report include those related to specific successes and issues associated with installing various configurations using iron with a bulking agent, and the suitability of these bulking agents for addressing contamination at specific sites. Bulking agents have been combined with iron for several reasons, including improving groundwater flow conditions within the reactive zone, treatment of additional contaminants not addressed by iron alone, and reducing project cost.

Passive Reactive Barrier at Oak Ridge National Laboratory, Oak Ridge, Tennessee

Site Name: Oak Ridge National Laboratory	**Location:** Oak Ridge, Tennessee
Period of Operation: August 1997 to Ongoing (data available through August 1999)	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Two demonstrations of PRB technology to treat groundwater contaminated with uranium	**Cleanup Type:** Field demonstration
Contaminants: Radioactivity • Uranium concentrations in groundwater ranging as high as 1.7 mg/L to 2.6 mg/L	**Waste Source:** Storage of uranium-contaminated liquid waste in ponds
Technical Contact: William Goldberg MSE Technology Applications Telephone: (406) 494-7330 **DOE Contract:** Scott McMullin DOE/OST/Savannah River Operations Office Telephone: (803) 725-9596	**Technology:** PRBs • Two PRBs installed to intercept two pathways of the shallow groundwater contaminant plume - funnel-and-gate PRB (FGPRB) and trench PRB (TPRB) • FGPRB - Sand-filled collection trench that is 220 ft long and 25 ft deep- two wing walls used to funnel groundwater to treatment zone; collection side and discharge side separated by a HDPE impermeable barrier installed vertically in middle of the trench - Two treatment systems demonstrated; (1) treatment train of three 55-gal canisters run in series - pH adjustment using magnesium hydroxide, iron and gravel; ZVI for uranium removal; iron and peat mixture for nitrate removal; (2) electrochemical cell - one 55-gal drum equipped with electrodes at the top and bottom and filled with ZVI; applied current used to increase groundwater pH to increase reductive capacity of the iron - Buildup of hydraulic head in discharge portion of PRB required installation of pumps in the treatment area to move groundwater through the system • TPRB - 225 long and 30 ft deep groundwater capture trench installed subparallel to groundwater flow with an impermeable barrier on downgradient side of the trench; groundwater flows through a section of reactive iron media in the middle of the trench (26ft long by 2 ft wide by 30 ft deep) then discharged through gravel backfill - Buildup of hydraulic head in discharge portion of PRB required the trench to be extended and an enhancement zone to be constructed to provide sufficient gradient to overcome the hydraulic buildup **Type/Quantity of Media Treated:** Groundwater • Shallow groundwater - unconsolidated zone; relatively low hydraulic gradient • Deep groundwater - bedrock • Soil is 20-30 ft thick; relatively low permeability except at transition zone (weathered and fractured bedrock between soil and competent bedrock) FGPRB - 133,000 gal of groundwater treated TPRB - 200,000 to 400,000 gal of groundwater treated

Passive Reactive Barrier at Oak Ridge National Laboratory, Oak Ridge, Tennessee (continued)

Regulatory Requirements/Cleanup Goals:
- The objective of the demonstrations were to reduce the amount of contaminant reaching Bear Creek through the two pathways in the shallow groundwater
- No specific cleanup levels identified for the demonstration

Results:
- FGPRB
  - Uranium concentrations in groundwater reduced 80 to 99.6%
  - Reduction of secondary contaminants 75% for nitrate and 42% for sulfate
- TPRB
  - Uranium concentrations in groundwater reduced about 90%
  - Reduction of secondary contaminants highly variable
- Low hydraulic gradient and recharge from the deep aquifer affected the performance of the PRBs by causing buildup of hydraulic head on the downgradient side of the trenches adversely impacted the hydraulic operation and treatment effectiveness of the systems

Costs:
- Actual installation costs for the FGPRB demonstration were $943,000; costs for long term O&M are under development
- Costs for the TPRB had not been fully developed and were therefore not included in the report

Description:
The S-3 Ponds at the Oak Ridge National Laboratory, Oak Ridge Reservation Y-12 Plant in Oak Ridge, Tennessee were used for the disposal of uranium-contaminated waste. These waste disposal activities resulted in three contaminant migration pathways at the site - two in the shallow groundwater and one in the deep groundwater. Demonstrations of two PRB systems were conducted at the site to treat the two contaminant pathways from the shallow groundwater. Uranium concentrations in the shallow groundwater ranged as high as 1.7 mg/L to 2.6 mg/L.

The two technologies demonstrated were FGPRB and TPRB, using reactive iron as the treatment media. Data from two years of operation (August 1997 to August 1999) show that uranium concentrations in groundwater were reduced by as much as 96.6% by the FGPRB and 90% by the TPRB. During this time, the FGPRB treated about 133,000 gallons of groundwater and the TPRB treated between 200,000 and 400,000 gallons of groundwater. During the demonstrations, buildup of hydraulic head on the downgradient side of the trenches adversely impacted the hydraulic operation and treatment effectiveness of the systems and system modifications were performed to address the problem. The systems are continuing to operate.

Phytoremediation at Aberdeen Proving Grounds, Edgewood Area J-Field Site, Edgewood, MD

Site Name: Aberdeen Proving Grounds, Edgewood Area J-Field Site	**Location:** Edgewood, MD
Period of Operation: Spring 1996 - Ongoing (data available through 1998)	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Long-term field demonstration of phytoremediation for treatment of chlorinated solvents in groundwater	**Cleanup Type:** Field demonstration
Contaminants: Chlorinated Solvents - 1,1,2,2-TCA, TCE, DCE at levels up to 260 ppm	**Waste Source:** Open burning/detonation of munitions

Technical Contacts Harry Compton U.S. EPA, ERT (MS101) 2890 Woodbridge Avenue Edison, NJ 08837-3679 Tel: 732-321-6751 Fax: 732-321-6724 E-mail: compton.harry@epa.gov Steve Hirsh U.S. EPA, Region 3 (3HS50) 1650 Arch Street Philadelphia, PA 19103-2029 Tel: 215-814-3352 E-mail: hirsh.steven@epa.gov	**Technology:** Phytoremediation Demonstration area is approximately 2,034 m^2 and contains 156 viable poplars Two-year-old hybrid poplars were planted 5 to 6 ft in Spring 1996; surficial drainage was installed to remove precipitation quickly and allowed trees to reach groundwater New trees were planted in October 1998 to increase the phytoremediation area and assess the usefulness of native species for phytoremediation **Type/Quantity of Media Treated:** Groundwater Contamination is 5 to 40 ft bgs plume is slow-moving due to tight soils and silty sand

Regulatory Requirements/Cleanup Goals:
Provide hydraulic influence of the groundwater plume and mass removal of contaminants; no quantitative cleanup goals were identified

Results:
Sampling was performed for groundwater; sap flow monitoring; tree transpiration gas and condensate sampling; and exposure pathway assessments
Groundwater level data indicated that hydraulic influence is occurring, with the trees currently removing 1,091 gpd and at the end of 30 years expected to remove 1,999 gpd
Contaminated plume has not migrated off-site during the growing seasons
Contaminant uptake is minimal at this time but expected to improve as the trees mature

Costs:
Capital costs of $80/tree including $5,000 for initial site preparation, additional $80,000 for UXO clearance of soil during planting; O&M costs: $30,000

Phytoremediation at Aberdeen Proving Grounds, Edgewood Area J-Field Site, Edgewood, MD (continued)

Description:
Aberdeen Proving Grounds is located at the tip of the Gunpowder Neck Peninsula in Edgewood Maryland. At APG, the Army practiced open trench (toxic pits) open burning/detonation of munitions containing chemical agents and dunnage from the 1940s to the 1970s. Large quantities of decontaminating agents containing solvents were used during the operation, and the surficial groundwater table was contaminated with solvents (1,1,2,2-TCA, TCE, DCE) at levels up to 260 ppm. A demonstration of phytoremediation to clean up shallow groundwater was performed at the site was performed by the U.S. Air Force (USAF) as part of the Department of Defense's (DOD's) Environmental Security Technology Certification Program (ESTCP), and the SITE Program.

At the APG site, a process called deep rooting was used to achieve hydraulic influence. Hybrid poplar trees were planted in the spring of 1996 at five to six feet bgs to maximize groundwater uptake. The field demonstration and evaluation will be for a five year period. The U.S. Geological Survey has estimated that hydraulic influence will occur when 7,000 gallons of water per day are removed from the site. The latest field data indicates that hydraulic influence is occurring. Current tree uptake is 1,091 gpd and is expected to increase to 1,999 gpd at the end of 30 years. Contaminant uptake is minimal at this time but is expected to improve as the trees mature. Groundwater sampling indicates that the contaminated plume has not migrated off-site during the growing season and sampling data showed non-detectable emissions from transpiration gas. There are several on-going studies to determine if deleterious compounds retained in the leaves and soil could pose risks to environmental receptors. Cost for site preparation included additional costs for UXO clearance, for a total of $80/tree, with O&M costs of $30,000 per year.

Phytoremediation at Carswell Air Force Base, Fort Worth, TX

Site Name: Carswell Air Force Base	**Location:** Fort Worth, Texas
Period of Operation: Spring 1996 - Ongoing (data available through 2001)	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Long-term field demonstration of phytoremediation for treatment of chlorinated solvents in groundwater	**Cleanup Type:** Field demonstration
Contaminants: Chlorinated Solvents • TCE	**Waste Source:** Manufacture and assembly of military aircraft
Greg Harvey U.S. Air Force, ASC/EMR 1801 10th Street - Area B Wright Patterson AFB, OH Tel: 937-255-7716 ext. 302 Fax: 937-255-4155 E-mail: Gregory.Harvey@wpafb.af.mil	**Technology:** Phytoremediation • In April 1996, 660 eastern cottonwoods were planted in a one acre area • Two sizes of trees were planted - whips and 5-gallon buckets **Type/Quantity of Media Treated:** Groundwater • Shallow (under 12 ft) aerobic aquifer

Regulatory Requirements/Cleanup Goals:
- Provide hydraulic containment and removal of contaminants
- Reduce mass of TCE in the aquifer transported across the downgradient end of the site by 30 % during the second growing season and by 50 % during the third growing season, as compared to baseline TCE mass flux calculations

Results:
- Root biomass and extent were examined in September of 1997 (the second growing season)
- In September 1997, the roots of both the whips and caliper trees had reached the water table and the depth distribution of the roots was similar
- The maximum reduction in the outflow of contaminated groundwater that could be attributed to the trees was approximately 11 %, and was observed at the peak of the third growing season
- Preliminary field data collected during the fifth dormant season (January 2001) indicate that the trees were beginning to have a widespread effect on groundwater geochemistry, reducing dissolved oxygen content beneath the trees to less than 1 mg/L

Costs:
The total cost for site preparation was $22,000, site work $171,200, and annual O&M $2,000, in addition to costs for research level monitoring.

Phytoremediation at Carswell Air Force Base, Fort Worth, TX (continued)

Description:
Groundwater at the U.S. Air Force Plant 4 (AFP4) and adjacent Naval Air Station, Fort Worth, Texas, has been contaminated with chlorinated solvents from operations associated with the manufacture and assembly of military aircraft. . A demonstration of phytoremediation to clean up shallow groundwater was performed at the site was performed by the U.S. Air Force (USAF) as part of the Department of Defense's (DOD's) Environmental Security Technology Certification Program (ESTCP), and the SITE Program.

The first three growing seasons at Carswell resulted in a remediation system that reduced the mass of contaminants moving through the site. The maximum observed reduction in the mass flux of TCE across the downgradient end of the site during the demonstration period was 11 percent. Increases in hydraulic influence and reductive dechlorination of the dissolved TCE plume are expected in out years, and may significantly reduce the mass of contaminants. Modeling results indicate that hydraulic influence alone may reduce the volume of contaminated groundwater that moves offsite by up to 30 percent. The decrease in mass flux that can be attributed to *in situ* reductive dechlorination has yet to be quantified. The total cost for site preparation was $22,000, site work $171,200, and annual O&M $2,000, in addition to costs for research level monitoring.

Phytoremediation at Edward Sears Site, New Gretna, NJ

Site Name: Edward Sears Site	**Location:** New Gretna, NJ
Period of Operation: December 1996 - Ongoing (data available through 1999)	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Long-term field demonstration of phytoremediation for treatment of chlorinated solvents in groundwater	**Cleanup Type:** Field demonstration
Contaminants: Chlorinated Solvents and Xylene • Maximum concentrations in groundwater – dichloromethane (490,000 ppb), PCE (160 ppb), TCE (390 ppb), trimethylbenzene (TMB) – (2,000 ppb),xylenes (2,700 ppb)	**Waste Source:** Leaking drums and containers
George Prince U.S. EPA, ERT (MS101) 2890 Woodbridge Avenue Edison, NJ 08837-3679 Tel: 732-321-6649 Fax: 732-321-6724 E-mail: prince.george@epa.gov	**Technology:** Phytoremediation • In December 1996, 118 hybrid poplar trees were planted 9 ft bgs in a plot approximately one-third of an acre in size; in addition, some trees were planted along the boundary of the site at 3 ft bgs (shallow rooted) to minimize groundwater and rainwater infiltration from off-site • The trees were planted 10 ft apart on the north to south axis and 12.5 ft apart on the east-west axis • Site maintenance involves fertilization, and control of insects, deer and unwanted vegetation • Over 40 direct push microwells were installed to monitor groundwater **Type/Quantity of Media Treated:** Groundwater • Highly permeable sand layer from 0 to 5 ft bgs, underlain by a much less permeable layer of sand, silt, and clay from 5 to 18 ft bgs • Most of the contamination is confined from 5 to 18 ft bgs

Regulatory Requirements/Cleanup Goals:
Provide hydraulic containment and removal of contaminants; no quantitative cleanup goals identified

Results:
- Dichloromethane was reduced over the first 3 years of monitoring, with concentrations at 4 locations decreasing from 490,000 down to 615 ppb, 12,000 ppb to ND, 680 ppb to ND, and 420 to 1.2 ppb
- PCE was reduced at 1 location from 100 to 56 ppb
- TCE increased at 1 location from 9 to 35 ppb, but decreased at another location from 99 to 42 ppb; at other locations TCE remained stable over the 3 year period
- Trimethylbenzene was reduced from 147 to 2 ppb, 246 to ND, 1900 to 50 ppb, and 8 to 1 ppb at four microwell points in the treated area; at another well point within the treated area, concentrations of TMB were relatively unaffected, 102 ppb in August 1997 compared to 128 in August 1999
- Xylenes were unaffected or slightly increased at 1 location, 26 ppb in August 1997 compared to 34 ppb in August 1999; at two other locations, xylene concentrations dropped from 590 to 17 ppb, and from 56 to 1.4 ppb

Costs:
The total cost for installation was $105,000, consisting of $24,000 for site preparation, $65,700 for planting; and $15,300 for maintenance

Phytoremediation at Edward Sears Site, New Gretna, NJ (continued)

Description:
From the mid-1960s to the early 1990s, the Edward Sears property was used for the repackaging and sale of paints, adhesives, paint thinners, and various military surplus materials. The soil and groundwater were contaminated with a variety of contaminants, including dichloromethane, PCE, TCE, TMB, and xylenes. A demonstration of phytoremediation to clean up shallow groundwater was performed at the site was performed by the U.S. Air Force (USAF) as part of the Department of Defense's (DOD's) Environmental Security Technology Certification Program (ESTCP), and the SITE Program.

At the Edward Sears site, a process called deep rooting was used to achieve hydraulic influence. Hybrid poplar trees were planted in late 1996 at 9 ft bgs in a plot of one-third acre, with performance measured for 3 years (a fourth year of monitoring is planned). There were substantial reductions in dichloromethane and TMB concentrations during the 1998 growing season. For example, dichloromethane was reduced to 615 parts per billion (ppb) from 490,000 ppb at one location and to a non-detect level from up to 12,000 ppb at another location; TMB was reduced to 50 ppb from 1,900 at one location. There is also indication of anaerobic dechlorination in the root zone as the level of PCE dropped and TCE increased. The total cost for installation was $105,000, consisting of $24,000 for site preparation, $65,700 for planting; and $15,300 for maintenance. Groundwater monitoring will continue into 2002.

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

Site Name: Alpine Cleaners; Dry Clean USA #11401; Former American Uniform; One Hour Dry Cleaners	**Location:** Alpine Cleaners, OR; Dry Clean USA #11401, Boca Raton, FL; Former American Uniform, Hutchinson, KS; One Hour Dry Cleaners, Coral Springs, FL
Period of Operation: Alpine Cleaners - 5 years (dates not specified) Dry Clean USA #11401 - October, 2000 to September, 2001 Former American Uniform - Not specified One Hour Dry Cleaners - August, 2000 to August, 2001	**Cleanup Authority:** State
Purpose/Significance of Application: Full-scale remediation of chlorinated solvents in soil and groundwater at drycleaner facilities using SVE and air sparging	**Cleanup Type:** Full scale
Contaminants: Chlorinated Solvents • PCE soil concentrations varied among the sites and ranged from 0.01 to 12 mg/kg. Soil at one site was also contaminated with TCE-, cis-1,2-DCE • PCE groundwater concentrations varied among the sites and ranged from 0.08 to 127 mg/L. Some sites reported other chlorinated organics in the soil such as TCE and cis-1,2-DCE. Two sites reported that DNAPLs were present or likely to be present.	**Waste Source:** Waste and wastewater from drycleaning operations

Contacts: Varied by site	**Technology:** SVE and Air Sparging • SVE systems consisted of from 2 to 9 vapor extraction wells applying a vacuum of 3 to 123 inches of water and drawing 186 to 4,500 scfm of soil vapor at depths from 2 to15 feet bgs. • Air sparging systems consisted of from 2 to12 sparging wells supplying air at a pressure of 27 to 53 psig at a rate of 14 to 43 scfm at depths from 40 to 85 feet bgs.
	Type/Quantity of Media Treated: Soil and Groundwater • Groundwater plumes areas ranged from 24,000 to 96,000 square feet

Regulatory Requirements/Cleanup Goals:
Soil
• Cleanup goals were based on state regulatory standards and included 0.2 mg/kg PCE and 0.03 mg/kg leachable PCE
Groundwater
• Cleanup goals were based on state regulatory goals or drinking water MCLs, and ranged from 0.003 to 0.3 mg/L PCE. Cleanup goals for other contaminants were not provided..

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

Results:
Alpine Cleaners - The PCE groundwater plume continued to spread, although at a slow rate. PCE concentrations exceeded the treatment goal of less than 0.003 mg/L in several monitoring wells. The remediation system removed approximately 390 pounds of VOCs during 5 years of operation. The removal of VOCs leveled off after approximately 2 years of operation.
Dry Clean USA #11401 - Approximately 23.7 pounds of contaminants were removed from the subsurface. Total chlorinated ethylene concentrations in shallow- and intermediate-depth source area monitoring wells decreased by 2-3 orders of magnitude. However, cis-1,2-DCE concentrations rose two orders of magnitude in the deep-source area monitoring well. Five wells still contained contaminant concentrations exceeding MCLs.
Former American Uniform - The SVE system achieved cleanup goals to remediate the source area vadose zone. Significant reductions in the concentrations of chlorinated VOCs in the groundwater were observed, including a decrease in PCE concentrations. However, rebounding PCE concentrations were observed 6-months after the remediation was completed. The SVE system removed 221 lbs of PCE.
One Hour Dry Cleaners - Through August of 2001, approximately 4 pounds of contaminants were removed from the subsurface. Contaminant concentrations in source area monitoring wells were reduced two orders of magnitude.

Costs:
Design and implementation costs ranged from \$28,000 to \$240,000; annual O&M costs ranged from \$16,000 to \$200,000.

Description:
SVE and air sparging was conducted at four drycleaner sites contaminated with chlorinated organic compounds from leaks, spills, or dumping of drycleaning solvents or wastewaters. Although all of the treatment systems removed contaminants from the subsurface, only one treatment achieved cleanup goals. Reported design and implementation costs ranged from \$28,000 to \$240,000. Reported annual O&M costs ranged from \$16,000 to \$200,000.

In Situ Chemical Oxidation at Six Drycleaner Sites, Various Locations

Site Name:	Location:
Butler Cleaners #1; Butler Cleaners #2; Former Quick-N-Easy Wash-O-Mat and Former Artistic Cleaners (these two facilities contributed to the same groundwater plume); Hanner's Cleaners; Paul's Classic Dry Cleaners; Swift Cleaners	Butler Cleaners #1, Jacksonville, FL; Butler Cleaners #2, Jacksonville, FL; Former Quick-N-Easy Wash-O-Mat and Former Artistic Cleaners, Wichita, KS; Hanner's Cleaners, Pompano Beach, FL; Paul's Classic Dry Cleaners, WI; Swift Cleaners, Jacksonville, FL
Period of Operation: Butler Cleaners #1 - ongoing (dates not specified) Butler Cleaners #2 - October, 1999 Former Quick-N-Easy Wash-O-Mat and Former Artistic Cleaners - 1999 Hanner's Cleaners - June to September, 2000 Paul's Classic Dry Cleaners - Not specified Swift Cleaners - July 1999	**Cleanup Authority:** State
Purpose/Significance of Application: Demonstration of *in situ* oxidation technologies for remediation of chlorinated solvents in groundwater at drycleaner facilities	**Cleanup Type:** Field demonstration
Contaminants: Chlorinated Solvents • All of the sites were contaminated with PCE and TCE • Concentrations varied by site ranging with concentrations ranging from 1 to 42 mg/L for PCE and 0.02 to 012 mg/L for TCE • Five sites reported that DNAPLs were present or likely to be present.	**Waste Source:** Waste and wastewater from drycleaning operations

Contacts:
Varied by site

Technology:
In situ chemical oxidation:
- At the Butler Cleaners #1, Butler Cleaners #2, and Former Quick-N-Easy Wash-O-Mat and Former Artistic Cleaners sites, solutions of potassium permanganate were injected into the subsurface to oxidize contaminants. At two sites the solutions were mixtures of potassium permanganate with water, with potassium permanganate making up 8% to 15% of the solution. At one site, the solution was heated and tertiary butyl alcohol was added to help mobilize the contaminants. The solutions were injected through from one to 45 wells, and injection volumes ranged from 1,000 to 2,200 gallons. At two of the sites SVE was also used to remove contaminants from the soil.
- At the Hanner's Cleaners and Swift Cleaners sites, solutions of water, hydrogen peroxide (12 to 25%), and an unspecified catalyst were injected into the subsurface to oxidize contaminants. The solutions were injected through from 6 to 12 wells, and volumes ranged from 1,700 to 20,000 gallons. SVE was also used at both sites to remove contaminants from the soil.
- At the Paul's Classic Dry Cleaners site, a field demonstration of an ozone in-well air sparging system was conducted. The treatment system consisted of a single well where sequential sparging and groundwater recirculation functions were performed in the sparge well. The system delivered an air and ozone gas mixture (the composition of the mixture was not specified) at a rate of 1.7 to 2.2 cfm first to the lower sparge point, then the in-well sparge point, each for a specified period of time. In-well pumping was then performed. This process was repeated in a cycle over a period of 16-18 hours/day. Multi-phase extraction was also conducted at the site.

Type/Quantity of Media Treated:
Groundwater
- Reported plume areas ranged from 130,000 to 1.3 million square feet, and reported plume depths ranged from 25 to 75 feet bgs. Reported actual treatment areas ranged from 400 to 7,900 square feet, and reported actual treatment depths ranged from 30 to 45 feet.

Regulatory Requirements/Cleanup Goals:
- Cleanup goals were based on state regulatory goals or EPA MCLs.
- Specified cleanup goals included 0.005 to 0.014 mg/L for PCE and 0.012 mg/L for TCE

Results:
Only one site (Swift Cleaners) reported achieving remediation goals. Other sites reported that contaminant concentrations were not significantly reduced or that cleanup goals were not met.

Costs:
Reported design and implementation costs:
- Potassium permanganate systems - $105,000 to $230,000
- Hydrogen peroxide - $110,000 to $170,000
- Ozone sparging - Not specified

Description:
In situ chemical oxidation was conducted at six drycleaner sites contaminated with chlorinated solvents from drycleaning operations with TCE and PCE as the primary contaminants in groundwater. At three sites solutions of potassium permanganate were injected into the subsurface, at two sites solutions of hydrogen peroxide and catalyst were injected into the subsurface, and at one site an ozone in-well air sparging system was installed. Only one site (Swift Cleaners) reporting achieving remediation goals. Other sites reported that contaminant concentrations were not significantly reduced or that cleanup goals were not met.

Multi-Phase Extraction or Pump and Treat at Five Drycleaner Sites, Various Locations

<table>
<tr><td colspan="2">Site Name:
Former Big B Cleaners; Former Sta-Brite Cleaners; Johannsen Cleaners; Koretizing Cleaners; Nu Way II Cleaners</td><td>Location:
Former Big B Cleaners, Warrington, FL; Former Sta-Brite Cleaners, Sarasota, FL; Johannsen Cleaners, Lebanon, OR; Koretizing Cleaners, Jacksonville, FL; Nu Way II Cleaners, OR</td></tr>
<tr><td colspan="2">Period of Operation:
Former Big B Cleaners - March to August, 2000 and November, 2000 to January, 2001
Former Sta-Brite Cleaners - June to August, 2001
Johannsen Cleaners - Not provided
Koretizing Cleaners - March to October, 2001
Nu Way II Cleaners - Three years (remediation reported to be ongoing, specific dates not specified).</td><td>Cleanup Authority:
State</td></tr>
<tr><td colspan="2">Purpose/Significance of Application:
Use of multi-phase extraction or pump and treat to cleanup soil and groundwater contaminated with chlorinated solvents from drycleaning operations</td><td>Cleanup Type:
Full scale</td></tr>
<tr><td colspan="2">Contaminants:
Chlorinated Solvents
• 3 of 4 sites contaminated with PCE and TCE in soil and groundwater; one contaminated with PCE only
• Concentrations in groundwater varied by site ranging from 3 to 3,400 mg/L for PCE and 1 to 42 mg/L for TCE.
• DNAPLs were present or likely to be present at 4 sites; LNAPL reported at one site
• Three sites also had soil contamination, with concentrations of PCE ranging from 76 to 37,000 mg/L. Contamination of soil with other chlorinated VOCs, such as TCE, and VCE, was also reported.</td><td>Waste Source:
Waste and wastewater from drycleaning operations</td></tr>
<tr><td>Contacts:
Varied by site</td><td colspan="2">Technology:
Multi-phase extraction:
• Multi-phase extraction was applied at Former Big B Cleaners; Former Sta-Brite Cleaners; Johannsen Cleaners; and Koretizing Cleaners
• At the Former Big B Cleaners site, the treatment system consisted of two soil vapor extraction (SVE) wells installed in horizontal trenches 1.5 feet in depth and one groundwater capture well.   A vacuum of 73 inches of water was applied to the SVE wells, resulting in an extracted air flow rate of 102 cfm. The groundwater well design pumping rate was 10 gpm. The groundwater treatment system was a packed tower air stripper. Residual VOCs were treated with a granular activated carbon system.
• At the Former Sta-Brite Cleaners site, the treatment system consisted of 8 recovery wells installed to depths of 17 to 19 feet bgs. The design vacuum of the system was 10 inches of mercury and 70 cfm.
• At the Johannsen Cleaners Site, the treatment system consisted of two horizontal headers with vertical wells to the groundwater table. The system removed soil vapor and groundwater treated them using air stripping or direct discharge to the atmosphere.
• At the Koretizing Cleaners Site, the treatment system consisted of 7 extraction wells to remove groundwater and soil vapor. Groundwater and soil vapor removed rates were 2 gpm and 175 scfm, respectively. Extracted vapors were treated using granular activated carbon and extracted groundwater was treated using a low-profile air stripper.
Pump-and Treat
• At the Nu Way II Cleaners site, the treatment system consisted of one LNAPL extraction well and one groundwater extraction well operating at 10-15 gal./min. Extracted groundwater was treated with an oil/water separator, air stripper, and carbon adsorption sand discharge to a local POTW.</td></tr>
</table>

Multi-Phase Extraction or Pump and Treat at Five Drycleaner Sites, Various Locations (continued)

Type/Quantity of Media Treated:
Groundwater and Soil
- Groundwater plume areas ranged from 0.27 to 17 acres. The deepest reported plume went to 92 feet below ground surface. Actual treatment areas ranged from 6,000 to 150,000 cubic feet for groundwater treatments.

Regulatory Requirements/Cleanup Goals:
At 3 sites the reported cleanup goals for groundwater were the drinking water MCL for PCE or TCE (less than 0.003 mg/L). For soil the cleanup goals were reported as leachability-based levels for PCE (less than 0.03 mg/kg). No cleanup goals were reported for the Johannsen Cleaners site. At the Nu Way II Cleaners site, no numeric cleanup goals were reported, but the goals removal of the contaminant source and protection or mitigation of threats to human health and the environment were reported.

Results:
- At the Former Big B Cleaners site, 215 pounds of PCE were removed from the unsaturated zone, and post-treatment PCE levels were below detection limits 9 of 14 samples. Post-treatment PCE concentrations in groundwater were not specified.
- At the Former Sta-Brite Cleaners site, an estimated 150 pounds of contaminant mass was removed during the first 3 months of operation. Additional performance data are not provided.
- Treatment results were not provided for the Johannsen Cleaners site.
- At the Koretizing Cleaners site, 24 pounds of contaminant were removed, and the concentrations of chlorinated ethenes were reduced by approximately 2 orders of magnitude.
- At the Nu Way II Cleaners site, 40 pounds of VOCs and 50 pounds of petroleum hydrocarbons were removed.

Costs:
Reported design and implementation costs:
- Former Big B Cleaners - $61,000
- Former Sta-Brite Cleaners - $130,000
- Johannsen Cleaners - estimated $60,000 to $85,000
- Koretizing Cleaners - $245,000
- Nu Way II Cleaners - Not specified

Description:
Multi-phase extraction was conducted at four drycleaner sites and pump and treat 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 215 pounds of PCE removed at the Former Big B Cleaners site.

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EX SITU GROUNDWATER TREATMENT ABSTRACTS

Pump and Treat and Soil Vapor Extraction at the Commencement Bay South Tacoma Channel Superfund Site, Tacoma, WA

Site Name:
Commencement Bay South Tacoma Channel Superfund Site

Location:
Tacoma, WA

Period of Operation:
November, 1998 - Ongoing (data available through June 2000)

Cleanup Authority:
CERCLA - Remedial Action
- ROD signed 1985

EPA Contact:
Remedial Project Manager:
Kevin Rochlin
U.S. EPA Region 10
1200 Sixth Avenue
Seattle, WA 98101
Phone: (206) 553-2106
rochlin.kevin@epa.gov

Purpose/Significance of Application:
Remediation of groundwater and soil contaminated with chlorinated VOCs using pump and treat and SVE

Cleanup Type:
Full scale

Contaminants:
Chlorinated Volatile Organic Compounds (VOCs)
- 1,1,2,2-Tetrachloroethane (PCA) - 17 to 300 μg/L
- trans-1,2-Dichloroethene (DCE) - 30 to 100 μg/L
- Trichloroethene (TCE) - 54 to 130 μg/L
- Tetrachloroethene (PCE) - 1.6 to 5.4 μg/L
- vinyl chloride (concentration not specified)
- The presence of light and dense non-aqueous phase liquids has been confirmed at the site

Waste Source:
Oil recycling, paint and lacquer thinner manufacturing, oil canning, and heating, ventilation, and air conditioning equipment warehousing

Pump and Treat System Operation Contractor:
URS Greiner, Inc. (URSG)
(Point of contact not provided)

SVE System Contractor:
Environmental Science and Engineering, Inc.
(Point of contact not provided)

Technology:
Pump and Treat of Groundwater:
- Groundwater extraction began in November, 1988 using a single well designed to yield 500 gallons per minute (gpm). In August 1995, 4 additional wells designed to yield 50 gpm each also began extracting groundwater.
- extracted groundwater is treated using two granular activated carbon (GAC) adsorption vessels connected in series, each of which contain about 20,000 pounds of GAC.

Soil Vapor Extraction (SVE)
- The SVE system consisted of 23 vapor extraction wells in the vadose zone and a carbon adsorption system to treat the vapors.
- The design air flow rate for the system was 3,000 standard cubic feet per minute.
- The SVE system operated between August1993 and May1997.

Type/Quantity of Media Treated:
Groundwater and Soil
- 450 million gallons of groundwater treated through May 2000

Regulatory Requirements/Cleanup Goals:
- Groundwater extraction rate (100 to 500 gpm)
- Aquifer remedial goals in μg/L - PCA (0.219), PCE (5), TCE (5), trans-1,2-DCE (100), cis-1,2-DCE (70), vinyl chloride (2)
- Performance standard for reinjection of treated groundwater in μg/L - PCA (10.7), PCE (8.85), TCE (80.7), trans-1,2-DCE (1.85), vinyl chloride (100), total VOCs (193)
- Performance standard for discharge of treated groundwater to surface water in μg/L - PCA (6.48), PCE (4.15), TCE (55.6), trans-1,2-DCE (32,800), vinyl chloride (2.92)
- Performance standards for the SVE system were not specified.

Pump and Treat and Soil Vapor Extraction at the Commencement Bay South Tacoma Channel Superfund Site, Tacoma, WA (continued)

Results:
- Actual groundwater extraction rate is less than 100 gpm. Iron fouling likely is a primary cause of the low extraction rate.
- About 15,000 pounds of VOCs had been removed from groundwater by the pump and treat system through December 2000.
- As of June 2000, concentrations of PCA, TCE, and total-1,2-DCE in the extraction wells remained above the remedial goals. Information on the concentrations of other contaminants were not provided.
- The size of the TCE and DCE contaminant plumes have decreased from 1993 to 1998.
- The above ground treatment system routinely met performance standards.
- The RPM indicated that the current pump and treat system will not attain the aquifer remedial goals due to the presence of light and dense non-aqueous phase liquids.
- The SVE system removed approximately 54,100 pounds of VOCs from subsurface soils at the site.

Costs:
Pump and Treat System:
- Total capital costs through May, 2000 were $1.8 million
- Total year 2000 operating costs were $0.41 million

Cost information was not provided for the SVE system.

Description:
From the 1920s to 1976 site operations included oil recycling and manufacturing of thinner for paint and lacquer. From 1976 to 1995, site operations were limited to canning new oil brought to the site in bulk containers. The facility has been used as a warehouse for heating, ventilation, and air conditioning equipment since 1995. Both shallow soil, subsurface soil, and groundwater at the site were contaminated with volatile organic compounds (VOCs), including chlorinated solvents.

SVE was used from 1993 to 1997 to treat soil at the site. A pump and treat system for groundwater was installed and began operating in 1988. Operation of the pump and treat system was ongoing as of June, 2000. Through December 2000, the pump and treat system had removed about 15,000 pounds of VOCs, and the SVE system had removed another 54,100 pounds of VOCs during its operation. However, the presence of light and dense non-aqueous phase liquids provide continuing sources of dissolved phase contaminants, and remedial goals for the aquifer are not expected to be met using pump and treat. Future plans for the site are being evaluated to determine the optimal approach to address site-related contamination.

Pump and Treat, *In Situ* Chemical Oxidation, and Soil Vapor Extraction at the Union Chemical Company Superfund Site, South Hope, ME

Site Name:
Union Chemical Company (UCC) Superfund Site

Location:
South Hope, Maine

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

Cleanup Authority:
CERCLA - Remedial Action
- ROD signed 1990; ESD signed 1995

Remedial Project Manager:
Terry Connelly
US EPA Region 1
1 Congress Street, Suite 1100
Boston, MA 02114-2023
Phone: (617) 918-1373
E-mail: connelly.terry@epa.gov

Purpose/Significance of Application:
Use of a combination of pump and treat, SVE, and *in situ* chemical oxidation to treat groundwater and soil contaminated with chlorinated and non-chlorinated VOCs

Cleanup Type:
Full scale

Contaminants:
Chlorinated Solvents, VOCs
- Maximum initial concentrations of contaminants in groundwater during RI: TCE (84,000 µg/L), TCA (73,000 µg/L), 1,1-DCE (2,700 µg/L), 1,1-DCA (12,000 ug/L), 1,1,1-TCA (73,000 ug/L)

Waste Source:
Solvent manufacturing and reclamation operations

State Contact:
Rebecca Hewett
MEDEP
17 State House Station
Augusta, ME 04333
Phone: (207) 287-2651
E-mail: rebecca.l.hewett@state.me.us

PRP Group:
Randy Smith
Union Chemical Trust
American Environmental Consultants
P.O. Box 310
Mont Vernon, NH 03057
Phone: (603) 673-0004
randycsmith1 @cs.com

Technology:
Pump and Treat of Groundwater:
- The groundwater extraction system consists of 28 wells, all screened in the shallow aquifer.
- The above-ground treatment system consists of: metals removal using precipitation; organics removal using air stripping, UV/oxidation, and granular activated carbon; and discharge of treated water to a nearby stream.
- Vapors from the water treatment units and the soil vapor extraction (SVE) unit treated with thermal oxidation prior to discharge to the atmosphere
- The groundwater monitoring network includes 109 wells. For each monitoring event, only approximately 20 wells were sampled and analyzed. From January 1996 through April 1998, the groundwater was monitored quarterly. After April 1998, groundwater monitoring was performed semi-annually.

Soil Vapor Extraction
- 91 hot air injection wells heat soils and increase volatilization
- 33 vapor extraction wells
- pump-and treat system and clay cap enhanced SVE by dewatering soils and minimizing discharge of surface water into the subsurface
- thermal oxidation of vapors from the water treatment units and the soil vapor extraction (SVE) unit prior to discharge to the atmosphere

In Situ Chemical Oxidation
- Injection of potassium permanganate in a two percent solution and sodium permanganate in a 20 to 40 % solution using existing groundwater extraction and monitoring wells

Type/Quantity of Media Treated:
Groundwater
- 8.4 million gallons of groundwater treated (January 1996 through December 1999)
- Shallow and bedrock aquifer systems
- 48,000 cubic yards of soil treated

Pump and Treat, In Situ Chemical Oxidation, and Soil Vapor Extraction at the Union Chemical Company Superfund Site, South Hope, ME (continued)

Regulatory Requirements/Cleanup Goals:
- Groundwater extraction rate of 5.1 gallons per minute
- 1,1-Dichloroethane (DCA) - 5 µg/L (groundwater), 0.5 µg/L (pump-and treat system discharge)
- Trichloroehtene (TCE) - 5 µg/L (groundwater), 0.5 µg/L (pump-and treat system discharge)
- 1,1-Dichloroethene (DCE) - 7 µg/L (groundwater), 0.5 µg/L (pump-and treat system discharge)
- 1,1,1-Trichloroethane (TCA) - 200 µg/L (groundwater), 0.5 µg/L (pump-and treat system discharge)

Results:
- From January 1996 through June 1999 about 9,600 pounds of VOCs were removed by the P&T and SVE systems
- In general, contaminant concentrations in the groundwater are decreasing over time
- Contaminant concentrations in the effluent from the pump and treat system were not above discharge criteria
- Contaminant mass reductions from chemical oxidation were estimated at 89% reduction for TCE and 47% reduction for 1,2-DCE, but an increase of 1,1-DCA of 79% was also observed
- Ethane concentrations are decreasing more rapidly than ethene concentrations because the ethenes are responding more rapidly to the permanganate additions

Costs:
- Total capital costs for the remediation in 1995 dollars was $9.5 million.
- Average annual O&M costs for the pump and treat and SVE systems was $0.6 million
- Average annual O&M cost for *in situ* chemical oxidation was $0.15 million

Description:
UCC operated from 1967 to 1986 as a producer and distributor of solvent for the removal of furniture finishes. Operations were expanded in 1969 to include solvent reclamation and recycling services; these services subsequently developed into UCCs primary business. Waste treatment operations were discontinued in 1984, at which time MEDEP and EPA removed from the site 2,000 drums, 30 liquid storage tanks containing 10,000 gallons of liquid waste and sludge, and some contaminated soil.

On-site soil and groundwater and an off-site stream had been contaminated with VOCs. The pump and treat system began operating in January 1996 and continued through December 1999. Pumping was resumed on a limited basis from July to October 2000. SVE was operated at the site since 1996 without any modifications. In October 1997 and June 1998 pilot-scale tests of *in situ* chemical oxidation using permanganate were performed at the site. Based on the results of those tests, in 1999 and 2000 *in situ* chemical oxidation was used on a ful-scale basis to treat groundwater at the site.

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EX SITU DEBRIS/SOLID MEDIA TREATMENT ABSTRACTS

Reactor Surface Contaminant Stabilization at the Hanford Site, C Reactor, Richland, WA

Site Name: Hanford Nuclear Site, C Reactor	**Location:** Richland, WA
Period of Operation: August 1997 - March 1998	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Field demonstration of surface coating to stabilize contaminated surfaces to avoid airborne contamination during decontamination and decommissioning	**Cleanup Type:** Field demonstration
Contaminants: Radioactivity	**Waste Source:** Nuclear reactor decommissioning

Management Contact: Jeff Bruggerman U.S. Department of Energy Phone: (509) 372-4029 **Technical Contact:** Greg Gervais U.S. Army Corps of Engineers Phone: (206) 764-6837 **Technology Vendors:** Don Koozer Master-Lee Engineering Phone: (509) 783-3523 Marc Azure RedHawk Environmental Phone: (509) 946-8606	**Technology:** Surface Treatment - Spray Applied Polymer Coatings • Two coating systems tested • Master-Lee system is a one-coating polymeric film 2.8 mm thick • Redhawk system is a two-coating - a polyurethane foam base layer covered by a polyurea film **Type/Quantity of Media Treated:** Debris • Initial test on rusted mild steel and stainless steel metal coupons measuring 7.6 centimeter (CM) x 7.6 cm x 1.5 mm • Demonstration test on 3 x 3 array of 9 nozzle assemblies on reactor face

Regulatory Requirements/Cleanup Goals:
- No specific cleanup goals identified for the demonstration
- Objectives of the demonstration included demonstrating complete coverage over complex shapes and greater performance than baseline technology, Rust-Oleum No. 769 coating
- Performance measurements included tests of adhesion, thermal aging, radiation aging, thermal cycling, biodegradation, air permaeability, and moisture permeability

Results:
- All three technologies tested (baseline, 1-coat, and 2-coat) passed performance tests for aging resistance
- The baseline technology and 1-coat processes demonstrated incomplete coverage over complex shapes
- The 2-coat process demonstrated complete coverage, and fast curing at ambient temperatures, but was more expensive and required additional labor and training to apply
- The baseline technology and 1-coat system may be applicable to flatter surfaces

Costs:
- Estimated costs to coat the entire reactor face (2,044 nozzle assemblies, 196 square meters) were $64,000 for the 2-coat system and $20,900 for the baseline

Reactor Surface Contaminant Stabilization at the Hanford Site C Reactor, Richland, WA (continued)

Description:

The Hanford Site produces nuclear material and components for weapons systems. The demonstration was conducted by the U.S. Department of Energy's Office of Science and Technology to evaluate their potential to stabilize contaminated surfaces, such as the face of a nuclear reactor, to avoid airborne contamination during decontamination and decommissioning activities.

The baseline coating and one-layer coating did not completely cover nozzle assemblies on the reactor face. However, the two-layer coating system, consisting of a base layer of foam covered by an outer layer of polymeric film, was successful. The baseline technology would cost about 33% as much as the innovative technology cost of $64,000 to stabilize the entire Hanford C reactor face, but the baseline system failed to provide complete surface coverage.

Lead TechXtract® Chemical Decontamination at the Hanford Site, Richland, WA

Site Name: U.S. Department of Energy Hanford Site	**Location:** Richland, WA
Period of Operation: May 1998	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Field demonstration of a process that uses ultrasonics and chemical baths to remove radioactive contaminants from surfaces	**Cleanup Type:** Field demonstration
Contaminants: Radioactivity • alpha and beta/gamma	**Waste Source:** Nuclear reactor decommissioning
Management Contact: Jeff Bruggerman U.S. Department of Energy Phone: (509) 372-4029 **Technical Contact:** Greg Gervais U.S. Army Corps of Engineers Phone: (206) 764-6837 **Technology Vendor:** W. Scott Fay Active Environmental Technologies, Inc. Phone: (609) 702-1500	**Technology:** Surface Treatment - Lead TechXtract® Chemical Decontamination • System included three heated ultrasonic baths, two rinse stations with vacuum drying, and a final vacuum drying station • Ultrasonic baths - electronically heated; 20 in. by 11.5 in. by 11 in.; first two baths contained surface preparation formulations; third bath contained an extraction blend containing chelating agents • Lead bricks were treated in batches of 4 bricks; batch dwell time was 7 minutes per bath for 13 batches and 5 minutes per batch for 7 batches **Type/Quantity of Media Treated:** Debris • 78 lead bricks, each measuring 5 cm x 10 cm x 20 cm

Regulatory Requirements/Cleanup Goals:
Radioactivity
- Alpha activity: < 20 dpm/100 cm^2 removable, <100 dpm/100 cm^2 total
- Beta/Gamma activity: <1,000 dpm/100 cm^2 removable, < 5,000 dpm/100 cm^2 total
- Treat bricks sufficiently so they can e recycled as scrap lead
- Decontamination rate of over 100 bricks per 5-hour day

Results:
- 78 out of 80 bricks processed met the treatment criteria for radioactivity in 3.5 hours, and could be recycled as scrap lead
- Production rate of 220 bricks per 5-hour day achieved
- Estimated secondary residual waste generated was 0.01 gallons per brick, or 6 pounds per ton treated

Costs:
- Estimated costs for treating the 1,956 lead bricks at the Hanford Site were $49,000, compared to $8,770 for the baseline technology of encapsulation and disposal in an on-site landfill.

Lead TechXtract® Chemical Decontamination at the Hanford Site, Richland, WA (continued)

Description:
A demonstration of the Lead TechXtract® chemical decontamination technology was conducted at DOE's Hanford Site. Radioactive-contaminated lead bricks from former Reactor C were used for the demonstration.

The Lead TechXtract® technology uses ultrasonics and chemical baths to remove radioactive contaminants from surfaces. Of the 80 bricks treated, 78 met the cleanup criteria that would allow the bricks to be recycled as scrap lead. The total cost to treat Hanford's inventory of 1,956 bricks using this technology was estimated to be $49,000. No modifications were identified as being needed for the technology for use at the Hanford Site C Reactor. Refinements such as adding a HEPA filter ventilation system to allow more highly contaminated bricks to be processed were identified.

En-Vac Robotic Wall Scabbler Demonstration at the Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID

Site Name: Idaho National Engineering and Environmental Laboratory (INEEL), Test Area North (TAN), Decon Shop	**Location:** Idaho Falls, ID
Period of Operation: March 2000	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Field demonstration of a robotic abrasive blasting to remove lead-based paint from concrete and steel walls and floors	**Cleanup Type:** Field demonstration
Contaminants: Lead	**Waste Source:** Concrete and steel surfaces coated with lead-based paint

Technology Demonstration: Bradley Freeze, D&D Program Manager Idaho National Engineering and Environmental Laboratory Phone: (208) 526-3775 E-mail: bjf@inel.gov **Vendor Contact:** Tom Maples MAR-COM, Inc. Phone: (503) 285-5871	**Technology:** Surface Treatment - En-Vac Robotic Wall Scabbler • The system consisted of a robot, a shot recycling unit, a filter, and a vacuum unit; capable of cleaning both horizontal and vertical surfaces • Blast media (abrasive steel grit or steel shot) were provided to the robot through the blast hose. The vacuum unit collected fugitive dust and emissions. Spent blast media and blast residue were returned from the robot to the recycling unit through a vacuum hose and the recycling unit separated the residue from the blast media. • Demonstration test area was 60 feet square **Type/Quantity of Media Treated:** Debris • 60 square feet

Regulatory Requirements/Cleanup Goals:

- Objectives of the demonstration included evaluating the En-Vac Robotic Wall Scabbler versus the baseline technology of Pentek VAC-PAC
- No cleanup levels were identified for the demonstration

Results:

- The robotic wall scabbler treated 60 square feet in 36 minutes. The baseline technology treated 45 square feet in 3 hours and 15 minutes
- Compared to the baseline technology, the robotic wall scabbler is heavier and cannot scabble close to obstructions, but has a higher treatment rate, and can scabble deeper on concrete.

Costs:

The capital cost of the system was approximately $390,000. Costs for mobilization/demobilization were $2,455, operation, $37.41 per square foot treated, and waste disposal, $150 per square foot treated.
The robotic wall scabbler was estimated to be less expensive than the baseline technology for projects larger than 1,500 square feet total with average wall sizes greater than 60 square feet.

En-Vac Robotic Wall Scabbler Demonstration at the Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID (continued)

Description:
Test Area North (TAN) if INEEL supported research into nuclear powered aircraft in the 1950s. Upon termination of this research, the areas' facilities were converted to support a variety of DOE research projects. The Decon Shop provided radiological decontamination of tools and small equipment from 1957 through 1987.

The En-Vac robotic wall scabbler was used to remove lead-based paint from 60 square feet of a concrete surface. The performance achieved was compared to that of a hand-held scabbling unit using a grinding technology. The robotic wall scabbler achieved lead-based paint removal in 36 minutes, at an estimated cost of $37.41 per square foot treated, plus $2,455 for mobilization/demobilization and $150 per square foot treated for disposal of treatment residuals.

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CONTAINMENT ABSTRACTS

Alternative Landfill Capping at Marine Corps Base Hawaii, Kaneohe Bay, HI

<table>
<tr><td colspan="2">Site Name:
Marine Corps Base Hawaii, Kaneohe Bay, HI</td><td>Location:
Marine Corps Base Hawaii, Kaneohe Bay, HI</td></tr>
<tr><td colspan="2">Period of Operation:
Installed in 1994 to ongoing (data available for first 16 months of operation)</td><td>Cleanup Authority:
RCRA</td></tr>
<tr><td colspan="2">Purpose/Significance of Application:
Demonstration of evapotranspiration landfill caps as alternatives to conventional RCRA covers</td><td>Cleanup Type:
Field demonstration</td></tr>
<tr><td colspan="2">Contaminants:
Not identified</td><td>Waste Source:
Not identified</td></tr>
<tr><td rowspan="2">Navy Contracts:
Mr. Charles Reeter
Naval Facilities Engineering Service Center
Phone: (805) 982-4991
E-Mail reetercv@nfesc.navy.mil

Mr. Jeff Heath
Naval Facilities Engineering Service Center
Phone: (805) 982-4991
E-Mail reetercv@nfesc.navy.mil</td><td colspan="2">Technology:
Containment - Alternative Landfill Cap
• Soil-based evapotranspiration (ET) cap with engineered structures that limited infiltration of precipitation
• Three infiltration designs tested: 20% enhancement of runoff, 40% enhancement of runoff, and conventional ET cap (control)
• Rainfall exceeds 25 inches per year at demonstration site</td></tr>
<tr><td colspan="2">Type/Quantity of Media Treated:
Soil</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
• Purpose of the demonstration was to demonstrate the effectiveness of alternative caps</td></tr>
<tr><td colspan="3">Results:
• After 16 months of operation, the relative amount of percolation, as a percentage of precipitation, averaged 2 percent for the ET cap plus enhanced runoff plots and 5% for the conventional ET cap</td></tr>
<tr><td colspan="3">Costs:
• Estimated capital costs for ET covers were $50,000 - $100,000 per acre
• Estimated capital costs for ET covers were lover than RCRA C or RCRA D caps and estimated to have lower operation and maintenance costs that conventional RCRA caps</td></tr>
<tr><td colspan="3">Description:
A demonstration was conducted at Marine Corps Base Hawaii, Kaneohe Bay to determine the effectiveness of ET caps as alternatives to conventional RCRA caps. Three demonstration caps were installed in 1994 - a conventional ET cap to serve as a control, an ET cap with 20% runoff control, and an ET cap with 40% runoff control. The performance of the designs were evaluated by comparing the field monitoring data with the predicted performance of the RCRA design using the EPA HELP model.

After 16 months, percolation rates (as a percentage of precipitation) averaged 5% for the control ET cap, and 2% for the ET cap plus runoff control plots, supporting the concept of infiltration control by increasing runoff and reducing percolation. The estimated capital costs for an ET cap were $50,000 - $100,000 per acre, lower than the estimated costs for conventional RCRA caps. In addition, the operation and maintenance costs for ET caps was expected to be lower than for conventional RCRA caps.</td></tr>
</table>

Demonstration of a Polymer Coating on Contaminated Soil Piles at Naval Shipyard Long Beach, CA

Site Name:
Naval Shipyard Long Beach

Location:
Long Beach, CA

Period of Operation:
September 1997 - July 1998

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Field demonstration of a polymer coating for a soil pile to contain petroleum vapors and protect against erosion

Cleanup Type:
Field Demonstration

Contaminants:
BTEX

Waste Source:
Contaminated soil piles at cleanup sites

Navy Contacts:
Mr. Dharam Pal
Phone: (805) 982-1671
E-mail: pald@nfesc.navy.mil

Mr. Jeff Heath
Phone: (805) 982-1600
E-mail: heathjc@nfesc.navy.mil

Technology:
Containment - SOIL-SEMENT® Polymer Coating
- Polymer emulsion; concentrate that was diluted with water prior to application
- Sprayed onto soil; dried for 2-3 hours; cured for 24 - 36 hours

Type/Quantity of Media Treated:
Soil
- 11,000 cubic yard soil pile

Regulatory Requirements/Cleanup Goals:
- No specific cleanup goals were identified for the demonstration
- Objectives of the cover were to contain petroleum vapors and protect against erosion

Results:
- SOIL-SEMENT® coating has been in place since 1997 and is reported to have endured numerous rainstorms and high winds without dust or erosion problems
- SOIL-SEMENT® was used to replace a plastic cover that had failed

Costs:
- Soil-Sement® costs for this application were $25,000
- Estimates to coat a soil pile with Soil-Sement® were 4 to 5 cents per square foot of surface area for an inactive pile and 5 to12 cents per square foot for an active pile

Description:
Stockpliles of soil at cleanup sites need to be covered to reduce particulate and vapor emissions and to protect against erosion and runoff. As an alternative to plastic covers, a polymer coating was tested on a soil pile at the Naval Shipyard in Long Beach CA. The demonstration, conducted by the Naval Facilities Engineering Service Center, in conjunction with the Naval Facilities South West Division involved testing the Soil-Sement® coating on an 11,000 cubic yard soil pile.

The Soil-Sement® was sprayed onto the pile and allowed to dry and cure. The coating has been in place since 1997 and has been reported to have been effective in controlling dust and erosion from the soil pile. The use of a polymer coating was found to be cost effective compared to a plastic cover and can be mixed into the soil for disposal.

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APPENDIX A

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Soil Vapor Extraction (33 Projects)					
Basket Creek Surface Impoundment Site, GA	Soil Vapor Extraction	Soil (*ex situ*)	BTEX (Toluene), Ketones (MIBK)	1992	1997
Camp Lejeune Military Reservation, Site 82, Area A, NC	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1995	1998
Commencement Bay, South Tacoma Channel Well 12A Superfund Site, WA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1992	1995
Davis-Monthan AFB, Site ST-35, AZ	Soil Vapor Extraction	Soil (*in situ*)	BTEX/TPH	1995	1998
Defense Supply Center Richmond, OU 5, VA	Soil Vapor Extraction (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1992	1998
Fairchild Semiconductor Corporation Superfund Site, CA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1989	1995
Fort Greely, Texas Tower Site, AK	Soil Vapor Extraction, Air Sparging, *In Situ* Bioremediation	Soil (*in situ*)	BTEX/TPH	1994	1998
Fort Lewis, Landfill 4, WA	Soil Vapor Extraction, Air Sparging	Soil (*in situ*)	Chlorinated Solvents, Metals	1994	1998
Fort Richardson, Building 908 South, AK	Soil Vapor Extraction	Soil (*in situ*)	BTEX/TPH	1995	1998
Hastings Groundwater Contamination Superfund Site, Well Number 3 Subsite, NE	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1992	1995
Holloman AFB, Sites 2 and 5, NM	Soil Vapor Extraction	Soil (*in situ*)	BTEX/TPH	1994	1998
Idaho National Engineering and Environmental Laboratory, ID	Soil Vapor Extraction (Soil Venting) (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1996	2000
Intersil/Siemens Superfund Site, CA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1988	1998
Luke Air Force Base, North Fire Training Area, AZ	Soil Vapor Extraction	Soil (*in situ*)	BTEX/TPH	1990	1995
McClellan Air Force Base, Operable Unit D, Site S, CA	Soil Vapor Extraction (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1993	1995
Multiple (7) Dry Cleaner Sites	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	Various years - starting 1998	Various years - 2001, 2002

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
NAS North Island, Site 9, CA	Soil Vapor Extraction (Photolytic Destruction) (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1997	1998
Patrick Air Force Base, Active Base Exchange Service Station, FL	Soil Vapor Extraction (Biocube™) (Field Demonstration)	Soil (*in situ*)	BTEX/TPH	1994	2000
Patrick Air Force Base, Active Base Exchange Service Station, FL	Soil Vapor Extraction (Internal Combustion Engine) (Field Demonstration)	Soil (*in situ*)	BTEX/TPH	1993	2000
Rocky Mountain Arsenal Superfund Site (Motor Pool Area - Operable Unit #18), CO	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1991	1995
Sacramento Army Depot Superfund Site, Burn Pits Operable Unit, CA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents - TCE, PCE, DCE	1994	1997
Sacramento Army Depot Superfund Site, Tank 2 (Operable Unit #3), CA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated and Non-Chlorinated Solvents	1992	1995
Sand Creek Industrial Superfund Site, Operable Unit 1, CO	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents - PCE, TCE	1993	1997
Seymour Recycling Corporation Superfund Site, IN	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1992	1998
Shaw AFB, OU 1, SC	Soil Vapor Extraction, Groundwater Containment	Soil (*in situ*)	BTEX/TPH	1995	1998
SMS Instruments Superfund Site, NY	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated and Non-Chlorinated Solvents	1992	1995
Stamina Mills Superfund Site, RI	Soil Vapor Extraction (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents	1999	2001
Tyson's Dump Superfund Site, PA	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated Solvents	1988	1998
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH	Soil Vapor Extraction (*In Situ* Enhanced Soil Mixing) (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents - TCE, DCE, TCA	1992	1997
U.S. Department of Energy, Savannah River Site, SC	Soil Vapor Extraction (Flameless Thermal Oxidation) (Field Demonstration)	Soil (*in situ*)	Chlorinated Solvents - TCE, PCE, TCA	1995	1997

EXHIBIT A-1. SUMMARY OF 313 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	Soil Vapor Extraction (Horizontal Wells) (Field Demonstration)	Soil (*in situ*) and Groundwater	Chlorinated Solvents	1988	2000
Vandenberg Air Force Base, Base Exchange Service Station, CA	Soil Vapor Extraction (Resin Adsorption) (Field Demonstration)	Soil (*in situ*)	BTEX/TPH	1994	2000
Verona Well Field Superfund Site (Thomas Solvent Raymond Road - Operable Unit #1), MI	Soil Vapor Extraction	Soil (*in situ*)	Chlorinated and Non-Chlorinated Solvents	1988	1995
Other *In Situ* Soil Treatment (27 Projects)					
Alameda Point, CA	Electrokinetics (Field Demonstration)	Soil	Metals	1997	2001
Argonne National Laboratory - East, IL	Phytoremediation (Field Demonstration)	Soil	Metals	1998	2000
Beach Haven Substation, Pensacola, FL	Electrokinetics (Field Demonstration)	Soil	Metals	1998	2000
Brodhead Creek Superfund Site, PA	Contained Recovery of Oily Waste	Soil	PAHs, Metals	1995	1998
Castle Airport, CA	Bioventing (Field Demonstration)	Soil	BTEX/TPH	1998	1999
Dover Air Force Base, Building 719, DE	Bioventing (Field Demonstration)	Soil	Chlorinated Solvents	1998	2000
Eielson Air Force Base, AK	Bioventing (Field Demonstration)	Soil	BTEX/TPH	1991	1995
Ensign-Bickford Company - OB/OD Area, CT	Phytoremediation	Soil	Metals	1998	2000
Former Mare Island Naval Shipyard, CA	*In Situ* Thermal Desorption (Field Demonstration)	Soil	PCBs	1997	2000
Fort Richardson Poleline Road Disposal Area, OU B, AK	Six Phase Heating (Field Demonstration)	Soil	Chlorinated Solvents	1997	2000
Hill Air Force Base, Site 280, UT	Bioventing	Soil	BTEX/TPH	1990	1995
Hill Air Force Base, Site 914, UT	Bioventing, Soil Vapor Extraction	Soil	BTEX/TPH	1988	1995
Lowry Air Force Base, CO	Bioventing	Soil	BTEX/TPH	1992	1995
Magic Marker, NJ and Small Arms Firing Range (SAFR) 24, NJ	Phytoremediation (Field Demonstration)	Soil	Metals	Magic Marker - 1997; Fort Dix - 2000	2002

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

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

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

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

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Rose Disposal Pit, MA	Rotary Kiln Incinerator	Soil	Chlorinated Solvents, Dioxins, PCBs	1994	1998
Rose Township Dump, MI	Infrared Incinerator	Soil	BTEX/TPH, Dioxins, PCBs	1992	1998
Sikes Disposal Pits, TX	Rotary Kiln Incinerator	Soil, Debris	Chlorinated Solvents, PAHs	1992	1998
Times Beach, MO	Rotary Kiln Incinerator	Soil, Debris	Dioxins, PCBs	1996	1998
Vertac Chemical Corporation, AR	Rotary Kiln Incinerator	Soil, Waste, Drums	Pesticides/Herbicides, Dioxins, PCBs	1992	1998
Thermal Desorption (25 Projects)					
Anderson Development Company Superfund Site, MI	Thermal Desorption	Soil	Semivolatile - Nonhalogenated (MBOCA), PAHs	1992	1995
Arlington Blending and Packaging Superfund Site, TN	Thermal Desorption	Soil	Pesticides/Herbicides, Metals	1996	2000
Cape Fear Superfund Site, NC	Thermal Desorption	Soil	Chlorinated Solvents, Metals	1998	2002
FCX Washington Superfund Site, NC	Thermal Desorption	Soil	Pesticides/Herbicides	1995	1998
Fort Lewis, Solvent Refined Coal Pilot Plant (SRCPP), WA	Thermal Desorption	Soil	PAHs	1996	1998
Letterkenny Army Depot Superfund Site, K Areas, OU1, PA	Thermal Desorption	Soil	Chlorinated Solvents, Metals	1993	2000
Lipari Landfill, Operable Unit 3, NJ	Thermal Desorption	Soil	Chlorinated Solvents, Metals	1994	2002
Longhorn Army Ammunition Plant, Burning Ground No. 3, TX	Thermal Desorption	Soil	Chlorinated Solvents	1997	2000
McKin Superfund Site, ME	Thermal Desorption	Soil	BTEX/TPH, PAHs	1986	1995
Metaltec/Aerosystems Superfund Site, Franklin Borough, NJ	Thermal Desorption	Soil	Chlorinated Solvents	1994	2001

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Naval Air Station Cecil Field, Site 17, OU 2, FL	Thermal Desorption	Soil	BTEX/TPH, PAHs	1995	1998
New Bedford Harbor Superfund Site, New Bedford, MA	Thermal Desorption (Field Demonstration)	Soil	PCBs	1996	2001
Outboard Marine Corporation Superfund Site, OH	Thermal Desorption	Soil	PCBs	1992	1995
Port Moller Radio Relay Station, AK	Thermal Desorption	Soil	BTEX/TPH	1995	1998
Pristine, Inc. Superfund Site, OH	Thermal Desorption	Soil	BTEX, PAHs, Pesticides, Dioxins, Chlorinated Solvents	1993	1995
Reich Farm, Pleasant Plains, NJ	Thermal Desorption	Soil	Chlorinated Solvents, Other Volatiles and Semivolatiles (not specified)	1994	2001
Reilly Industries Superfund Site, Operable Unit 3, IN	Thermal Desorption	Soil	BTEX/TPH	1996	2002
Re-Solve, Inc. Superfund Site, MA	Thermal Desorption	Soil	PCBs	1993	1998
Rocky Flats Environmental Technology Site, Mound Site, Golden, CO	Thermal Desorption	Soil	Chlorinated Solvents	1997	2001
Rocky Flats Environmental Technology Site, Trenches T-3 and T-4, CO	Thermal Desorption	Soil	Chlorinated Solvents, Radionuclides	1996	2000
Sand Creek Superfund Site, OU 5, CO	Thermal Desorption	Soil	Pesticides, Metals	1994	2000
Sarney Farm, Amenia, NY	Thermal Desorption	Soil	Chlorinated Solvents, Ketones, BTEX	1997	2001
TH Agriculture & Nutrition Company Superfund Site, GA	Thermal Desorption	Soil	Pesticides	1993	1995
Waldick Aerospaces Devices Superfund Site, NJ	Thermal Desorption	Soil	Chlorinated Solvents, BTEX/TPH, Metals	1993	1998
Wide Beach Development Superfund Site, NY	Thermal Desorption w/Dehalogenation	Soil	PCBs	1990	1995

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Other *Ex Situ* Soil Treatment (33 Projects)					
Bonneville Power Administration Ross Complex, Operable Unit A, WA	Land Treatment	Soil	PAHs	1994	1998
Brookhaven National Laboratory, NY	Physical Separation/Segmented Gate System	Soil	Radionuclides	2000	2001
Brown Wood Preserving Superfund Site, FL	Land Treatment	Soil	PAHs	1989	1995
Burlington Northern Superfund Site, MN	Land Treatment	Soil	PAHs, Methylene Chloride Extractable Hydrocarbons (TPH)	1986	1997
Dubose Oil Products Co. Superfund Site, FL	Composting	Soil	PAHs, BTEX (Toluene), Chlorinated Solvents - TCE	1993	1997
Envirocare of Utah, UT	Polyethylene Macroencapsulation (Field Demonstration)	Soil	Radionuclides	1996	1998
Fort Greely, UST Soil Pile, AK	Land Treatment	Soil	BTEX/TPH	1994	1998
Fort Polk Range 5, LA	Acid Leaching (Field Demonstration)	Soil	Metals	1996	2000
French Ltd. Superfund Site, TX	Slurry-Phase Bioremediation	Soil	BTEX, PAHs, Chlorinated Solvents	1992	1995
Idaho National Environmental and Engineering Laboratory (INEEL), ID	Physical Separation/Segmented Gate System	Soil	Radionuclides	1999	2001
Joliet Army Ammunition Plant, IL	Slurry-Phase Bioremediation (Field Demonstration)	Soil	Explosives/Propellants	1994	2000
King of Prussia Technical Corporation Superfund Site, NJ	Soil Washing	Soil	Metals	1993	1995
Los Alamos National Laboratory, NM	Physical Separation; Segmented Gate System	Soil	Radionuclides	1999	2000
Lowry Air Force Base, CO	Land Treatment	Soil	BTEX/TPH	1992	1995
Massachusetts Military Reservation, Training Range and Impact Area, Cape Cod, MA	Solidification/Stabilization	Soil	Metals, Lead	1998	2001

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Naval Construction Battalion Center Hydrocarbon National Test Site, CA	Land Treatment - Bioremediation (Field Demonstration)	Soil	BTEX/TPH	1996	1998
New Bedford Harbor Superfund Site, New Bedford, MA	Solidification/Stabilization (Field Demonstration)	Soil	PCBs	1995	2001
New Bedford Harbor Superfund Site, New Bedford, MA	Solvent Extraction (Field Demonstration)	Soil	PCBs	1996	2001
New Bedford Harbor Superfund Site, New Bedford, MA	Vitrification (Field Demonstration)	Soil	PCBs	1996	2001
Novartis Site, Ontario, Canada	Land Treatment (Field Demonstration)	Soil	Pesticides/Herbicides	1996	1998
Oak Ridge National Laboratory, TN	Vitrification (Field Demonstration)	Soil	Metals, Radionuclides	1997	2000
Pantex Plant, Firing Site 5, TX	Physical Separation; Segmented Gate System	Soil	Radionuclides	1998	2000
Peerless Cleaners, WI; Stannard Launders and Dry Cleaners, WI	Land Treatment - Bioremediation	Soil	Chlorinated Solvents	Not Provided	2001
RMI Titanium Company Extrusion Plant, OH	Solvent Extraction (Field Demonstration)	Soil	Metals, Radionuclides	1997	2000
Sandia National Laboratories, ER Site 228A, NM	Physical Separation; Segmented Gate System	Soil	Radionuclides	1998	2000
Sandia National Laboratories, ER Site 16, NM	Physical Separation; Segmented Gate System	Soil	Radionuclides	1998	2000
Scott Lumber Company Superfund Site, MO	Land Treatment	Soil	PAHs	1989	1995
Southeastern Wood Preserving Superfund Site, MS	Slurry-Phase Bioremediation	Soil	PAHs - Naphthalene, Benzo(a)pyrene	1991	1997
Sparrevohn Long Range Radar Station, AK	Solvent Extraction	Soil	PCBs	1996	1998
Stauffer Chemical Company, Tampa, FL	Composting (Field Demonstration)	Soil	Organochlorine Pesticides	1997	2001
Tonapah Test Range, Clean Slate 2, NV	Physical Separation; Segmented Gate System	Soil	Radionuclides	1998	2000

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Umatilla Army Depot Activity, OR	Windrow Composting (Field Demonstration)	Soil	Explosives/Propellants -TNT, RDX, HMX	1992	1995
Umatilla Army Depot Activity, OR	Windrow Composting	Soil	Explosives/Propellants -TNT, RDX, HMX	1994	1997
Drinking Water Treatment (3 Projects)					
Charnock Wellfield, Santa Monica, CA	Drinking Water Treatment (Field Demonstration)	Drinking Water	MTBE, VOCs	1998	2001
Lacrosse, KS	Drinking Water Treatment	Drinking Water	MTBE, BTEX/TPH	1997	2001
Rockaway, NJ	Drinking Water Treatment	Drinking Water	MTBE, Chlorinated Solvents, Volatiles-Nonhalogenated	1980	2001
Pump and Treat (44 Projects)					
Amoco Petroleum Pipeline, MI	Pump and Treat with GAC	Groundwater	BTEX/TPH	1988	1995
Baird and McGuire Superfund Site, MA	Pump and Treat with Air Stripping, Chemical Treatment, and Filtration	Groundwater	BTEX/TPH, PAHs, Pesticides/Herbicides, Metals	1993	1998
Bofors Nobel Superfund Site, OU 1, MI	Pump and Treat with Air Stripping, GAC, Chemical Treatment, Filtration, and UV/Oxidation	Groundwater	Chlorinated Solvents, Semivolatiles	1994	1998
City Industries Superfund Site, FL	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents, BTEX/TPH	1994	1998
Coastal Systems Station, AOC 1, FL	Chemical Reaction and Dissolved Air Flotation (Field Demonstration)	Groundwater	BTEX/TPH, Metals	1997	1998
Commencement Bay South Tacoma Channel Superfund Site, WA	Pump and Treat with Soil Vapor Extraction	Groundwater	Chlorinated Solvents	1998	2001
Commencement Bay, South Tacoma Channel Well 12A Superfund Site, WA	Pump and Treat with GAC	Groundwater	Chlorinated Solvents	1988	1995
Des Moines TCE Superfund Site, OU 1, IA	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1987	1998

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Former Firestone Facility Superfund Site, CA	Pump and Treat with Air Stripping, GAC, and Oil/Water Separation	Groundwater	Chlorinated Solvents	1986	1998
Ft. Drum, Fuel Dispensing Area 1595, NY	Pump and Treat with Air Stripping and GAC	Groundwater	BTEX/TPH	1992	1995
Fort Lewis Logistics Center, WA	Pump and Treat	Groundwater	Chlorinated Solvents	1995	2000
JMT Facility RCRA Site (formerly Black & Decker RCRA Site), NY	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1988	1998
Keefe Environmental Services Superfund Site, NH	Pump and Treat with Air Stripping and Coagulation/Flocculation	Groundwater	Chlorinated Solvents	1993	1998
King of Prussia Technical Corporation Superfund Site, NJ	Pump and Treat with Air Stripping, GAC, and Electrochemical Treatment	Groundwater	Chlorinated Solvents, BTEX/TPH, Metals	1995	1998
Langley Air Force Base, IRP Site 4, VA	Pump and Treat with Air Stripping	Groundwater	BTEX/TPH	1992	1995
LaSalle Electrical Superfund Site, IL	Pump and Treat with Air Stripping, GAC, and Oil/Water Separation	Groundwater	Chlorinated Solvents, PCBs	1992	1998
Lawrence Livermore National Laboratory (LLNL) Site 300 - General Services Area (GSA) Operable Unit, CA	Pump and Treat with Air Stripping and GAC; SVE	Groundwater	Chlorinated Solvents	1991	1998
Marine Corps Base, OU 1 and 2, Camp Lejeune, NC	Pump and Treat	Groundwater	Chlorinated Solvents, BTEX, Metals	1995	2001
Marine Corps Base, Campbell Street Fuel Farm, Camp Lejeune, NC	Pump and Treat	Groundwater	BTEX, Pesticide/ Herbicide (Ethylene dibromide)	1996	2001
McClellan Air Force Base, Operable Unit B/C, CA	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1988	1995
Mid-South Wood Products Superfund Site, AR	Pump and Treat with GAC, Filtration, and Oil/Water Separation	Groundwater	PAHs, Metals	1989	1998
Mystery Bridge at Hwy 20 Superfund Site, Dow/DSI Facility - Volatile Halogenated Organic (VHO) Plume, WY	Pump and Treat with Air Stripping; SVE	Groundwater	Chlorinated Solvents	1994	1998

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

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

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Sylvester/Gilson Road Superfund Site, NH	Pump and Treat with Air Stripping, Biological Treatment, Chemical Treatment, and Filtration; Cap; SVE; Vertical Barrier Wall	Groundwater	Chlorinated Solvents, Metals	1982	1998
Twin Cities Army Ammunition Plant, MN	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1987	1995
Union Chemical Company Superfund Site, ME	Pump and Treat with *In Situ* Chemical Oxidation and Soil Vapor Extraction	Groundwater and Soil	Chlorinated Solvents, Metals	1996	2001
United Chrome Superfund Site, OR	Pump and Treat with Chemical Treatment	Groundwater	Metals	1988	1998
U.S. Aviex Superfund Site, MI	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents, Diethyl Ether	1993	1998
U.S. Department of Energy Kansas City Plant, MO	Pump and Treat with Advanced Oxidation Processes	Groundwater	Chlorinated Solvents	1983	1995
U.S. Department of Energy Savannah River Site, A/M Area, SC	Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1985	1995
Western Processing Superfund Site, WA	Pump and Treat with Air Stripping and Filtration	Groundwater	Chlorinated Solvents, PAHs, Metals	1988	1998
***In Situ* Groundwater Bioremediation (32 Projects)**					
Abandoned Manufacturing Facility - Emeryville, CA	Bioremediation	Groundwater	Chlorinated Solvents, Metals	1997	2000
Avco Lycoming Superfund Site, PA	Bioremediation	Groundwater	Chlorinated Solvents, Metals	1997	2000
Balfour Road Site, CA; Fourth Plain Service Station Site, WA; Steve's Standard and Golden Belt 66 Site, KS	Bioremediation	Groundwater	BTEX/TPH	1995	1998
Brownfield Site, Chattanooga, TN (specific site name not identified)	Bioremediation	Soil and Groundwater	MTBE, BTEX/TPH	1999	2001
Contemporary Cleaners, Orlando. FL	Bioremediation (HRC)	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Cordray's Grocery, Ravenel, SC	Bioremediation (ORC)	Soil and Groundwater	MTBE, BTEX, PAHs	1998	2001
Dover Air Force Base, Area 6, DE	Bioremediation (DNAPL) (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2002
Dover Air Force Base, Area 6, DE	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2000
Edwards Air Force Base, CA	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2000
French Ltd. Superfund Site, TX	Bioremediation; Pump and Treat with Activated Sludge	Groundwater	Chlorinated Solvents	1992	1998
Gas Station, Cheshire, CT (specific site name not identified)	Bioremediation	Groundwater	MTBE, BTEX/TPH	1997	2001
Hanford Site, WA	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1995	2000
Hayden Island Cleaners, Portland, OR	Bioremediation (HRC)	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Idaho National Engineering and Environmental Laboratory, Test Area North, ID	Enhanced Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents, Radionuclides	1999	2002
ITT Roanoke Site, VA	Enhanced Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1998	Not Provided
Lawrence Livermore National Laboratory, CA	Bioremediation (Bench Scale)	Groundwater	MTBE	Not Provided	2001
Libby Groundwater Superfund Site, MT	Bioremediation; Pump and Treat	Groundwater	PAHs	1991	1998
Moffett Field Superfund Site, CA	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1986	2000
Multiple Dry Cleaner Sites	Bioremediation (HRC)	Groundwater	Chlorinated Solvents	Not Provided	2001
Naval Weapons Station Seal Beach, CA	Bioremediation (Field Demonstration)	Groundwater	BTEX/TPH	1997	2000
Pinellas Northeast Site, FL	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1997	1998
Savannah River Site, SC	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1992	2000
Service Station, CA (specific site name not identified)	Bioremediation (ORC)	Groundwater	MTBE, BTEX	Not Provided	2001

EXHIBIT A-1. SUMMARY OF 313 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 (ORC)	Groundwater	MTBE, BTEX	Not Provided	2001
Site A (actual name confidential), NY	Bioremediation; Air Sparging; SVE; Pump and Treat with Air Stripping	Groundwater	BTEX/TPH	1995	1998
South Beach Marine, Hilton Head, SC	Bioremediation	Groundwater	MTBE, BTEX, PAHs	1999	2001
Specific site name not identified	Bioremediation (Bench Scale)	Soil and Groundwater	MTBE	Not Provided	2001
Texas Gulf Coast Site, TX	Bioremediation	Groundwater	Chlorinated Solvents	1995	2000
U.S. Department of Energy Savannah River Site, M Area, SC	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1992	1997
U.S. Navy Construction Battalion Center, Port Hueneme, CA	Bioremediation (Field Demonstration)	Groundwater	MTBE, Volatiles-Nonhalogenated	1998	2001
Vandenberg Air Force Base, Lompoc, CA	Bioremediation (Field Demonstration)	Groundwater	MTBE	1999	2001
Watertown Site, MA	Bioremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2000
Other *In Situ* Groundwater Treatment (65 Projects)					
328 Site, CA	Multi-Phase Extraction	Groundwater	Chlorinated Solvents	1996	2000
Aberdeen Proving Grounds, Edgewood Area J - Field Site, MD	Phytoremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2002
Amcor Precast, UT	Air Sparging	Groundwater	BTEX/TPH	1992	1995
Brookhaven National Laboratory, NY	In-Well Air Stripping (Field Demonstration)	Groundwater	Chlorinated Solvents	1999	2002
Butler Cleaners, Jacksonville, FL	Chemical Oxidation ($KMnO_4$)	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Camp Lejeune Marine Corps Base, Bldg 25, Camp Lejeune, NC	*In Situ* Flushing (SEAR and PITT)	Groundwater	Chlorinated Solvents - PCE	1999	2001
Carswell Air Force Base, TX	Phytoremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2002
Confidential Manufacturing Facility, IL	Six Phase Heating	Groundwater	Chlorinated Solvents	1998	2000

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Defense Supply Center, Acid Neutralization Pit, VA	Multi-Phase Extraction (Field Demonstration)	Groundwater	Chlorinated Solvents	1997	2000
Eaddy Brothers, Hemingway, SC	Air Sparging/SVE	Soil and Groundwater	MTBE, BTEX, PAHs	1999	2001
Edward Sears Site, NJ	Phytoremediation (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2002
Eight Service Stations, MD (specific sites not identified)	Multi-Phase Extraction	Soil and Groundwater	MTBE, BTEX	1990	2001
Fernald Environmental Management Project, OH	*In Situ* Flushing (Field Demonstration)	Groundwater	Metals (Uranium)	1998	2001
Former Intersil, Inc. Site, CA	Permeable Reactive Barrier; Pump and Treat with Air Stripping	Groundwater	Chlorinated Solvents	1995	1998
Former Nu Look One Hour Cleaners, Coral Springs, FL	Air Sparging Recirculation Well (NoVOCs™)	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Former Sages Dry Cleaners, Jacksonville, FL	*In Situ* Flushing (Ethanol Co-solvent)	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Fort Devens, AOCs 43G and 43J, MA	Monitored Natural Attenuation	Groundwater	BTEX/TPH	1997	2000
Four Service Stations (specific site names not identified)	Air Sparging	Groundwater	MTBE, BTEX	1993	2001
Fry Canyon, UT	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Metals, Radionuclides	1997	2000
Gold Coast Superfund Site, FL	Air Sparging; Pump and Treat	Groundwater	Chlorinated Solvents	1994	1998
Hanford Site, 100-H and 100-D Areas, WA	Chemical Reduction/Oxidation (Field Demonstration)	Groundwater	Metals	1995	2000
Johannsen Cleaners, Lebanon, OR	Multi-Phase Extraction	Groundwater	Chlorinated Solvents - PCE	Not Provided	2001
Keesler Air Force Base Service Station, AOC-A (ST-06), MS	Monitored Natural Attenuation	Groundwater	BTEX/TPH, Metals	1997	2000
Kelly Air Force Base, Former Building 2093 Gas Station, TX	Monitored Natural Attenuation	Groundwater	BTEX/TPH	1997	2000

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Lawrence Livermore National Laboratory Gasoline Spill Site, CA	Dynamic Underground Stripping (Field Demonstration)	Groundwater	BTEX/TPH	1992	1995
Louisiana Army Ammunition Plant, LA	Monitored Natural Attenuation	Groundwater	Explosives	Not Provided	2001
Miamisburg, OH	Air Sparging/Soil Vapor Extraction	Soil and Groundwater	Chlorinated Solvents	1997	2001
Milan Army Ammunition Plant, TN	Constructed Wetlands (Field Demonstration)	Groundwater	Explosives/Propellants	1996	2000
Massachusetts Military Reservation, CS-10 Plume, MA	Recirculating Wells (UVB and NoVOCs) (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2002
Moffett Federal Airfield, CA	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	1998
Moffett Field Superfund Site, CA	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	2000
Monticello Mill Tailings Site, Monticello, UT	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Metals	1999	2001
Multiple Air Force Sites	Bioslurping (Field Demonstration)	Groundwater	TPH	Not Provided	2001
Multiple Air Force Sites	Monitored Natural Attenuation (Field Demonstration)	Groundwater	Chlorinated Solvents	1993	1999
Multiple Air Force Sites	Monitored Natural Attenuation (Field Demonstration)	Groundwater	BTEX/TPH	1993	1999
Multiple Dry Cleaner Sites	Air Sparging; Soil Vapor Extraction	Groundwater	Chlorinated Solvents	Not Provided	2001, 2002
Multiple Dry Cleaner Sites	Chemical Oxidation (Field Demonstration)	Groundwater	Chlorinated Solvents	1999	2001, 2002
Multiple Dry Cleaner Sites	Multi-Phase Extraction; Pump and Treat	Groundwater	Chlorinated Solvents; BTEX/TPH	Not Provided	2001, 2002
Multiple Dry Cleaner Sites	Surfactant/Cosolvent Flushing; Thermal Desorption; In-Well Air Stripping (Field Demonstration)	Groundwater	Chlorinated Solvents	Not Provided	2001

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Multiple Sites	Permeable Reactive Barrier - Continuous Reactive Wall (Full - scale and Field Demonstrations)	Groundwater	Chlorinated Solvents	1991	2002
Multiple Sites	Permeable Reactive Barrier - Continuous Reactive Wall (Full - scale and Field Demonstrations)	Groundwater	Metals	1997	2002
Multiple Sites	Permeable Reactive Barrier - Funnel and Gate Configuration (Full - scale and Field Demonstrations)	Groundwater	Chlorinated Solvents; BTEX/TPH; Metals	1995	2002
Multiple Sites	Permeable Reactive Barrier - Injection and Other Emerging Technologies (Full - scale and Field Demonstrations)	Groundwater	Chlorinated Solvents; Pesticides/Herbicides; Metals	1995	2002
Multiple Sites	Permeable Reactive Barrier - Iron with a Bulking Agent as a Reactive Media (Full - scale and Field Demonstrations)	Groundwater	Chlorinated Solvents; Metals	1995	2002
Naval Air Station, North Island, CA	In-Well Air Stripping (NoVOCs) (Field Demonstration)	Groundwater	Chlorinated Solvents	1998	2000
Naval Air Station, Pensacola, FL	*In Situ* Oxidation; Monitored Natural Attenuation	Groundwater	Chlorinated Solvents	1998	2001
Naval Air Station Pensacola, OU 10, FL	*In Situ* Oxidation; Fenton's Reagent (Field Demonstration)	Groundwater	Chlorinated Solvents	1998	2000
Naval Submarine Base, Kings Bay, GA	*In Situ* Oxidation; Fenton's Reagent	Groundwater	Chlorinated Solvents	1998	2000
Naval Submarine Base, Kings Bay, GA	*In Situ* Oxidation; Monitored Natural Attenuation	Groundwater	Chlorinated Solvents	1999	2001
Oak Ridge National Laboratory, TN	Permeable Reactive Barrier - Funnel and Gate Configuration and Trench (Field Demonstration)	Groundwater	Radionuclides	1997	2002
Pinellas Northeast Site, FL	Air Sparging - Dual Auger Rotary Steam Stripping (Field Demonstration)	Groundwater	Chlorinated Solvents	1996	1998
Pinellas Northeast Site, FL	Membrane Filtration - PerVap™ (Field Demonstration)	Groundwater	Chlorinated Solvents	1995	1998

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Portsmouth Gaseous Diffusion Plant, X-701B Facility, OH	*In Situ* Oxidation (Field Demonstration)	Groundwater	Chlorinated Solvents	1988	2000
RMI Titanium Plant, Ashtabula Environmental Management Project, OH	*In Situ* Flushing (WIDE) (Field Demonstration)	Groundwater and Soil	Chlorinated Solvents, Radionuclides	1999	2001
Scotchman #94, Florence, SC	Air Sparging; Pump and Treat	Groundwater	MTBE, BTEX, PAHs	1998	2001
Site 88, Building 25, Marine Corps Base Camp Lejeune, NC	Surfactant Flushing (SEAR) (Field Demonstration)	Groundwater	Chlorinated Solvents, BTEX/TPH	1999	2001
South Prudence Bay Island Park, T-Dock Site, Portsmouth, RI	Biosparging	Groundwater	BTEX	1998	2001
Sparks Solvents/Fuel Site, Sparks, NV	Multi-Phase Extraction	Soil and Groundwater	MTBE, Chlorinated Solvents, TPH	1995	2001
Tacony Warehouse, PA	Permeable Reactive Barrier; Pump and Treat	Groundwater	Chlorinated Solvents	1998	2000
Tinkham's Garage Superfund Site, NH	Multi-Phase Extraction	Groundwater	Chlorinated Solvents	1994	2000
U.S. Coast Guard Support Center, NC	Permeable Reactive Barrier	Groundwater	Chlorinated Solvents, Metals	1996	1998
U.S. Department of Energy Savannah River Site, A/M Area, SC	Air Sparging (Field Demonstration)	Groundwater	Chlorinated Solvents	1990	1995
Visalia Superfund Site, CA	Dynamic Underground Stripping (Field Demonstration)	Groundwater	PAHs (Creosote)	1997	2000
Debris/Solid Media Treatment (27 Projects)					
Alabama Army Ammunition Plant, AL	Transportable Hot-Gas Decontamination (Field Demonstration)	Debris/Solid Media	Explosives	1995	1998
Argonne National Laboratory - East, IL	Physical Separation (Scabbling) (Field Demonstration)	Debris/Solid Media	Radionuclides	Not Provided	2000
Argonne National Laboratory - East, IL	Physical Separation (Concrete Demolition) (Field Demonstration)	Debris/Solid Media	Radionuclides	1997	2000

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Argonne National Laboratory - West, Waste Area Group 9, OU 9-04, ID	Solidification/Stabilization (Phosphate Bonded Ceramics) (Field Demonstration)	Debris/Solid Media	Metals	Not Provided	2000
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	Centrifugal Shot Blast (Field Demonstration)	Debris/Solid Media	Radionuclides	1997	1998
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	Rotary Peening with Captive Shot (Field Demonstration)	Debris/Solid Media	Radionuclides	1997	1998
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	Roto Peen Scaler with VAC-PAC[R] System (Field Demonstration)	Debris/Solid Media	Radionuclides	1996	1998
Clemson University, SC	Solidification/Stabilization (Sintering) (Bench Scale)	Debris/Solid Media	Metals	1995	2000
Fernald Site, OH	Physical Separation (Soft Media Blasting) (Field Demonstration)	Debris/Solid Media	Radionuclides	1996	2000
Hanford Site, C Reactor, WA	Solidification/Stabilization (Polymer Coating) (Field Demonstration)	Debris	Radionuclides	1997	1998
Hanford Site, WA	Physical Separation (Concrete Grinder) (Field Demonstration)	Debris/Solid Media	Radionuclides	1997	2000
Hanford Site, WA	Physical Separation (Concrete Shaver) (Field Demonstration)	Debris/Solid Media	Radionuclides	1997	2000
Hanford Site, WA	Physical Separation (Concrete Spaller) (Field Demonstration)	Debris/Solid Media	Radionuclides	1998	2000
Hanford Site, WA	Solidification/Stabilization (Polyester Resins) (Field Demonstration)	Debris/Solid Media	Metals, Radionuclides	Not Provided	2000
Hanford Site, WA	Physical Separation (Ultrasonic Baths) (Field Demonstration)	Debris	Radionuclides	1998	1998
Idaho National Engineering and Environmental Laboratory, ID	Solidification/Stabilization (Innovative Grouting and Retrieval)	Debris/Solid Media	Radionuclides	1994	2000
Idaho National Engineering and Environmental Laboratory, Pit 2, ID	Solidification/Stabilization (Polysiloxane) (Field Demonstration)	Debris/Solid Media	Metals	1997	2000

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Idaho National Engineering and Environmental Laboratory, ID	Solidification/Stabilization (DeHg^{SM} Process) (Field Demonstration)	Debris/Solid Media	Metals	1998	2000
Idaho National Engineering and Environmental Laboratory, ID	Shot Blaster (Wall Scabbler) (Field Demonstration)	Debris	Metals	2000	2001
Idaho National Engineering and Environmental Laboratory, ID	Vitrification (Graphite Furnace) (Field Demonstration)	Debris/Solid Media	Metals, Radionuclides	1997	2000
Lawrence Livermore National Laboratory, CA	Chemical Reduction/Oxidation; Direct Chemical Oxidation (Field Demonstration)	Debris/Solid Media	Chlorinated Solvents, Explosives/Propellants	Not Provided	2000
Los Alamos National Laboratory, Technical Area 33, NM	Solidification/Stabilization (Field Demonstration)	Debris/Solid Media	Metals, Radionuclides	1997	2000
Los Alamos National Laboratory, NM	Solidification/Stabilization (ADA Process) (Field Demonstration)	Debris/Solid Media	Metals	1998	2000
Pacific Northwest National Laboratory, WA	Solidification/Stabilization (Sol Gel Process) (Bench Scale)	Debris/Solid Media	Metals	Not Provided	2000
Portsmouth Gaseous Diffusion Plant, OH	Solidification/Stabilization (ATG Process) (Field Demonstration)	Debris/Solid Media	Metals, Radionuclides	1998	2000
Savannah River Site, SC	Chemical Reduction/Oxidation (Acid Digestion) (Field Demonstration)	Debris/Solid Media	Radionuclides	1996	2000
STAR Center, ID	Vitrification (Plasma Process) (Field Demonstration)	Debris/Solid Media	Metals, Radionuclides	1993	2000
Containment (7 Projects)					
Dover Air Force Base, Groundwater Remediation Field Laboratory National Test Site, Dover DE	Vertical Engineered Barrier (Field Demonstration)	Groundwater	None	1996	2001
Lawrence Livermore National Laboratory (LLNL) Site 300 - Pit 6 Landfill OU, CA	Cap	N/A	Chlorinated Solvents, Radioactivity	1997	1998
Marine Corps Base Hawaii, HI	Alternative Landfill Cover (Field Demonstration)	Soil and Solid Waste	None	1994	1998

EXHIBIT A-1. SUMMARY OF 313 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Technology *	Media	Contaminants	Year Operation Began	Year Published
Naval Shipyard, CA	Alternative Polymer Soil Pile Cover (Field Demonstration)	Soil	None	1997	1998
Oak Ridge National Laboratory, TN	Frozen Soil Barrier (Field Demonstration)	Groundwater	Radionuclides	1996	2000
Sandia National Laboratory, Albuquerque, NM	Cap (Field Demonstration)	N/A	Not contaminated	1995	2001
U.S. Department of Energy, SEG Facilities, TN	Frozen Soil Barrier Technology (Field Demonstration)	Soil (*in situ*)	Not Applicable (not a contaminated site)	1994	1997

* Full scale unless otherwise noted

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

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