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Abstracts of Remediation Case Studies

VOLUME 2

Federal Remediation Technologies Roundtable

Prepared by the

Member Agencies of the Federal Remediation Technologies Roundtable

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Federal Remediation Technologies Roundtable

Environmental Protection Agency
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Department of Energy
Department of Interior
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NOTICE

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FOREWORD

This report is a collection of abstracts summarizing 17 case studies of site remediation projects prepared by federal agencies. The case studies, collected under the auspices of the Federal Remediation Technologies Roundtable, were undertaken to document the results and lessons learned from early technology applications. They will help establish benchmark data on cost and performance which should lead to greater confidence in the selection and use of cleanup technologies.

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

The case study reports and abstracts are organized by technology in a multi-volume set listed below. Remediation Case Studies, Volumes 1-4, and Abstracts, Volume 1, were published in March 1995, and contain 37 case studies. Remediation Case Studies, Volumes 5 and 6, and Abstracts, Volume 2, were published in July 1997, and contain 17 case studies. These 17 case studies cover recently completed full-scale remediations and large-scale field demonstrations. In the future, the set will grow through periodic supplements tracking additional progress with site remediation.

Remediation Case Studies, Volume 1:	Bioremediation, EPA-542-R-95-002; March 1995; PB95-182911
Remediation Case Studies, Volume 2:	Groundwater Treatment, EPA-542-R-95-003; March 1995; PB95-182929
Remediation Case Studies, Volume 3:	Soil Vapor Extraction, EPA-542-R-95-004; March 1995; PB95-182937
Remediation Case Studies, Volume 4:	Thermal Desorption, Soil Washing, and In Situ Vitrification, EPA-542-R-95-005, March 1995; PB95-182945
Remediation Case Studies, Volume 5:	Bioremediation and Vitrification, EPA 542-R-97-008, July 1997; PB97-177554
Remediation Case Studies, Volume 6:	Soil Vapor Extraction and Other In Situ Technologies, EPA 542-R-97-009, July 1997; PB97-177562

Abstracts of Remediation Case Studies, Volume 1:	EPA-542-R-95-001; March 1995
Abstracts of Remediation Case Studies, Volume 2:	EPA 542-R-97-010, July 1997; PB97-177570

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In addition, the case studies and case study abstracts are available on the internet through the Federal Remediation Technologies Roundtable (FRTR) home page at: http://www.frtr.gov. The FRTR home page provides links to individual FRTR members' home pages, and includes a search function. Case studies and abstracts prepared by EPA are also available through EPA's Cleanup Information Bulletin Board System (CLU-IN BBS). CLU-IN BBS is available through the internet at http://clu-in.com, or via modem at (301) 589-8366 (8 Data Bits, 1 Stop Bit, No Parity, VT-100 or ANSI; Voice help: (301) 589-8368). Case studies prepared by the U.S. Department of Energy (DOE) are available through the internet, on the Office of Science and Technology home page, at http://em-52.em.doe.gov/ifd/ost/pubs.htm, under Innovative Technology Summary Reports. Individual Reports prepared by DOE are available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; or to the public through the U.S. Department of Commerce, National Technical Information Service (NTIS), Springfield, VA 22161 ((703) 487-4650).

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1.0 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 (FRTR) are working jointly to publish case studies of full-scale remediation and demonstration projects. In March, 1995, the FRTR published a four-volume series of case study reports. At this time, the FRTR is publishing two additional volumes of case study reports, providing case studies of site cleanup projects using bioremediation, vitrification, soil vapor extraction, and other in situ technologies.

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). The case studies were prepared based on recommended terminology and procedures from the Guide to Documenting Cost and Performance for Remediation Projects (EPA-542-B-95-002; March 1995). They present available cost and performance information for full-scale remediation efforts and several large-scale demonstration projects. The case studies are meant to serve as primary reference sources, and contain information on site background and setting, contaminants and media treated, technology, cost and performance, and points of contact for the technology application. The studies contain varying levels of detail, reflecting the differences in the availability of data and information. Because full-scale cleanup efforts are not conducted primarily for the purpose of technology evaluation, data collection on technology cost and performance is often limited.

Tables 1 and 2 provide a project summary including information on technology used, contaminants and media treated, and project duration for bioremediation and vitrification, and soil vapor extraction and other in situ technologies, respectively. These tables also note highlights of the technology applications. Table 3 summarizes cost data, including information on quantity of media treated and contaminant removed. In addition, Table 3 shows a calculated unit cost for some projects, and identifies key factors potentially affecting project cost. While a summary of project costs is useful, it is difficult to compare costs for different projects because of site-specific factors and differences in level of detail. Cost data are shown on Table 3 as reported in the case studies, and have not been adjusted for inflation to a common year basis. The dollar values shown in Table 3 should be assumed to be dollars for the time period that the project was in progress (shown on Tables 1 and 2 as project duration).

The project costs shown in the second column of the table were compiled, where possible, according to an interagency Work Breakdown Structure (WBS).[1] The WBS specifies costs as 1) before-treatment costs, 2) after-treatment costs, or 3) treatment costs. (Table 3 provides some additional information on activities falling under each category.) In many cases, however, the available information was not sufficiently detailed to be broken down in this way.

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[1]Additional information on the contents of the WBS and on whom to contact for WBS and related information is presented in the Guide to Documenting Cost and Performance for Remediation Projects.

The column showing the calculated treatment cost provides a dollar value per unit of soil or groundwater treated and, where available, per pound of contaminant removed. Note that when calculated costs are available on a per cubic yard or per ton basis, costs cannot be converted back-and-forth due to limited availability of soil bulk density data, and, therefore, comparisons using the information in this column may be complicated.

Key factors that potentially affect project costs include economies of scale, concentration levels in contaminated media, required cleanup levels, completion schedules, and hydrogeological conditions. It is important to note that several projects in the case study series represent early applications, and the costs of these technologies are likely to decrease in the future as firms gain experience with design and operation.

Table 1. Summary of Remediation Case Studies: Bioremediation and Vitrification

Site Name, State (Technology)	Contaminants Treated				Media (Quantity)	Project Duration	Highlights
	BTEX and/or TPH	Chlorinated Aliphatics	PAHs	Historical Activity (Principal Contaminants)			
Bioremediation							
Burlington Northern Superfund Site, MN (Land Treatment)	●		●	Wood preserving of railroad ties (PAHs, Methylene Chloride Extractable Hydrocarbons)	Soil and Sludge (13,000 yd^3)	5/86 - 10/94	Full-scale application of land treatment at a creosote-contaminated site.
Dubose Oil Products Co. Superfund Site, FL (Composting)	●	●	●	Waste treatment, recycling, and disposal facility (PAHs, Toluene, TCE)	Soil (19,705 tons)	11/93 - 9/94	Full-scale application of composting to treat VOC- and PAH-contaminated soil.
Southeastern Wood Preserving Superfund Site, MS (Slurry-Phase Bioremediation)			●	Wood preserving with creosote (Naphthalene, Benzo(a)pyrene)	Soil and Sludge (14,140 tons)	1991 - 1994	Full-scale application of slurry-phase bioremediation to treat soil with relatively elevated levels of PAHs.
Umatilla Army Depot Activity, OR (Windrow Composting)				Munitions (TNT, RDX, HMX)	Soil (10,969 yd^3)	3/94 - 9/96	Full-scale application of windrow composting to biodegrade explosives-contaminated soils.
U.S. Department of Energy Savannah River Site, SC (In Situ Bioremediation)		●		Nuclear material production and research (TCE, PCE)	Soil and Groundwater (not provided)	2/92 - 4/93	Demonstration combining biodegradation (sparging and biostimulation) with SVE to remediate both soil and groundwater contaminated with VOCs.
U.S. Department of Energy Paducah Gaseous Diffusion Plant, KY (Lasagna™ Soil Remediation)		●		Nuclear weapons production/uranium enrichment (TCE)	Soil and Soil Pore Water (not provided)	1/95 - 5/95	Demonstration of an in situ technology suited to sites with low permeability soils that combines several technologies to remediate soil and soil pore water contaminated with soluble organic compounds.
Vitrification							
Parsons Chemical/ETM Enterprises Superfund Site, MI (In Situ Vitrification)				Agricultural chemicals mixing, manufacturing, and packaging (Pesticides, Metals, Dioxins)	Soil and Sediment (3,000 yd^3)	5/93 - 5/94	First application of ISV at a Superfund site.
U.S. Department of Energy Hanford Site, WA, Oak Ridge (TN), and Others (In Situ Vitrification)		●		Hanford - Nuclear materials production; Others - Not provided (pesticides, metals, dioxin/furan, PCBs)	Soil, Sludge, and Debris (ranged from 3,100-5,600 tons)	Information not provided	Full-scale and field demonstrations of ISV for variety of media types and variety of contaminants.

Key:

BTEX - Benzene, Toluene, Ethylbenzene, and Xylene
TPH - Total Petroleum Hydrocarbons

Table 2. Summary of Remediation Case Studies: Soil Vapor Extraction and Other In Situ Technologies

Site Name, State (Technology)	Contaminants Treated				Media (Quantity)	Project Duration	Highlights
	BTEX and/or TPH	Chlorinated Aliphatics	Non-chlorinated Aliphatics	Historical Activity (Principal Contaminants)			
Soil Vapor Extraction (SVE)							
Basket Creek Surface Impoundment Site, GA (SVE)	●	●	●	Illegal disposal of liquid refinery and other hazardous wastes (Toluene, MIBK)	Soil (1,600 yd^3)	9/92 - 4/93	SVE was performed after low-permeability soil was excavated (ex situ SVE).
Sacramento Army Depot Superfund Site, Burn Pits Operable Unit, CA (SVE)		●		Army support - Burn Pits (TCE, PCE, DCE)	Soil (247,900 yd^3)	5/94 - 9/95	SVE system combining injection and extraction wells in a complex subsurface.
Sand Creek Industrial Superfund Site, Operable Unit No. 1, CO (SVE)	●	●		Pesticide manufacturing, petroleum refinery (PCE, TCE)	Soil (31,440-52,920 yd^3)	9/93 - 4/94	SVE system combining injection and extraction wells.
Enhancements/Additions							
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH (In Situ Enhanced Soil Mixing)		●		Waste Treatment Plant (TCE, TCA, DCE)	Soil (not provided)	6/92	Field demonstration of four technologies used to remediate fine-grained soils, including enhancing SVE performance.
U.S. Department of Energy Savannah River Site, SC (Flameless Thermal Oxidation)		●		Nuclear material production and research (TCE, PCE, TCA)	Off-Gases (not provided)	4/95 - 5/95	Field demonstration of an alternative technology for treatment of extracted vapors during an SVE application.
U.S. Department of Energy, Savannah River Site, SC, and Hanford Site, WA (Six Phase Soil Heating)		●		Nuclear material production and research (TCE, PCE)	Soil and Sediment (not provided)	10/93 - 1/94	Field demonstration of technology used to enhance removal of contaminants from clayey soil during an SVE application.
Other In Situ Technologies							
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH, and Other Sites (Hydraulic and Pneumatic Fracturing)		●		Tinker AFB - Underground Storage Tank Others - not provided (VOCs, DNAPLs, product)	Soil and Groundwater (not provided)	7-91 - 8/96 (multiple demonstrations during this period)	Field demonstrations of technology used to increase hydraulic conductivity, contaminant mass recovery, and radius of influence (for example, in a SVE application).
U.S. Department of Energy, SEG Facilities, TN (Frozen Soil Barrier Technology)				Not applicable (not a contaminated site)	Soil (35,694 ft^3)	5/94 - 10/94	Field demonstration of technology used to control waste migration in soils.
U.S. Department of Energy, Multiple Sites (ResonantSonic Drilling)				Not applicable (not a contaminated site)	Soil and Sediment (not provided)	1992 - 1994	Multiple field demonstrations of alternative drilling technology that in some applications may be less costly and produce less drilling waste than cable tool or mud rotary technologies.

Key:
MIBK - Methyl Isobutyl Ketone
TCE - Trichloroethene
PCE - Tetrachloroethene
DCE - 1,2-Dichloroethene
TCA - 1,1,1-Trichloroethane

Table 3. Remediation Case Studies - Summary of Cost Data

Site Name, State (Technology)	Project Cost ($)*	Quantity Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment**	Key Factors Potentially Affecting Project/Technology Costs***
Bioremediation					
Burlington Northern Superfund Site, MN (Land Treatment)	Not provided	13,000 yd^3	Not provided	Not provided	Not provided.
Dubose Oil Products Co. Superfund Site, FL (Composting)	$7,736,700 (T and B combined - information not available to segregate T from B)	19,705 tons	Not provided	Not calculated	Total costs for this project were relatively high because they include costs to excavate and temporarily store approximately 39,000 tons of additional soil that did not require treatment.
Southeastern Wood Preserving Superfund Site, MS (Slurry-Phase Bioremediation)	T - $2,400,000 A - $500,000	14,140 tons (10,500 yd^3)	Not provided	$170/ton ($230/yd^3)	The need for technology research and development, soil screening, slurry preparation, and slurry dewatering increased unit costs for this application.
Umatilla Army Depot Activity, OR (Windrow Composting)	T - $1,989,454 B+A - $3,141,652	10,969 yd^3	Not provided	$181/$yd^3$	The semi-arid cool climate, and ready availability of amendments, at UMDA contributed to lower costs for preparatory site work and composting.
U.S. Department of Energy Savannah River Site, SC (In Situ Bioremediation)	Not provided	Not provided	17,000 lbs VOCs	Not provided	Demonstration project: Capital costs are higher for in situ bioremediation (ISB) than for pump and treat (PT) with SVE because of need to install horizontal wells and for gas mixing and injection equipment. However, treatment time for ISB is estimated as 3 years compared with 10 years for PT with SVE.

Project Cost*
T = Costs for treatment activities, including preprocessing, capital equipment, operation, and maintenance
B = Costs for before-treatment activities, including site preparation, excavation, and sampling and analysis
A = Costs for after-treatment activities, including disposal of residuals and site restoration
C = Capital costs
O = Annual operating costs

Calculated Cost for Treatment**
**Calculated based on costs for treatment activities (T): excludes costs for before- (B) and after- (A)treatment activities. Calculated costs shown as "Not Calculated" if an estimate of treatment costs unavailable.

***For full-scale remediation projects, this identifies factors affecting actual project costs. For demonstration-scale projects, this identifies generic factors which would affect project costs for a future application using this technology.

Table 3. Remediation Case Studies - Summary of Cost Data (Continued)

Site Name, State (Technology)	Project Cost ($)*	Quantity Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment**	Key Factors Potentially Affecting Project/Technology Costs***
U.S. Department of Energy Paducah Gaseous Diffusion Plant, KY (Lasagna™ Soil Remediation)	Not provided	Not provided	Not provided	$40-90/yd^3 (projected)	Demonstration project: Capital costs are driven by costs for electrode construction. The ability to place treatment zones and electrodes in relatively close spacing and at reasonable cost are key drivers for technology cost-effectiveness.
Vitrification					
Parsons Chemical/ETM Enterprises Superfund Site, MI (In Situ Vitrification)	T - $800,000 B - $800,000 A - $164,000	5,400 tons (3,000 yd^3)	Not provided	$148/ton ($267/yd^3) (based on cost ceiling)	Relatively high soil moisture content contributed to higher unit cost for in situ vitrification treatment.
U.S. Department of Energy Hanford Site, WA, Oak Ridge (TN), and Others (In Situ Vitrification)	Not provided	Parsons: 4,800 tons Wasatch: 5,600 tons Private Superfund Site: 3,100 tons	Not provided	Generic project costs in the range of $375-425/ton; site-specific costs not provided	Multiple projects: In general, unit costs for in situ vitrification are affected by the local price of electricity, consumables, labor, mobilization and startup, and facilities modifications.

Project Cost*
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Table 3. Remediation Case Studies - Summary of Cost Data (Continued)

Site Name, State (Technology)	Project Cost ($)*	Quantity Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment**	Key Factors Potentially Affecting Project/Technology Costs***
Soil Vapor Extraction					
Basket Creek Surface Impoundment Site, GA (SVE)	T - 660,000 B - 1,300,000 A - 220,000	1,600 yd^3	72,084 lbs	$413/$yd^3$ ($275/ton) $9.20/lb VOC	This project addressed treatment of a relatively small quantity of highly-contaminated soil.
Sacramento Army Depot Superfund Site, Burn Pits Operable Unit, CA (SVE)	T - 670,500 B - 195,000	247,900 yd^3	138 lbs	$2.70/$yd^3$ $4,858/lb VOC	This project addressed treatment of a relatively large quantity of less-contaminated soil.
Sand Creek Industrial Superfund Site, Operable Unit No. 1, CO (SVE)	T - 2,058,564 B - 81,231	31,440-52,920 yd^3	176,500 lbs	$39-65/$yd^3$ $11.70/lb VOC	The calculated unit costs varied depending on how the soil quantity treated was estimated (larger estimates of soil quantity treated lead to lower unit costs).
Enhancements/Additions					
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH (In Situ Enhanced Soil Mixing)	C - 1,956,000 O - 20,000/day	Not provided	Not provided	$150-200/$yd^3$ (projected)	Demonstration project: Technology costs vary based on required materials and equipment.
U.S. Department of Energy Savannah River Site, SC (Flameless Thermal Oxidation)	C - 50,000	Not provided	Not provided	$0.72/lb VOC destroyed (projected)	Demonstration project: Heating content of off-gas and economies-of-scale are key factors affecting cost.
U.S. Department of Energy, Savannah River Site, SC, and Hanford Site, WA (Six Phase Soil Heating)	Not provided	Not provided	Not provided	$86/$yd^3$ (projected)	Demonstration project: Diameter and depth of plume, energy demand, and type of contaminants are key factors affecting cost.

Project Cost*
T = Costs for treatment activities, including preprocessing, capital equipment, operation, and maintenance
B = Costs for before-treatment activities, including site preparation, excavation, and sampling and analysis
A = Costs for after-treatment activities, including disposal of residuals and site restoration
C = Capital costs
O = Annual operating costs

Calculated Cost for Treatment**
**Calculated based on costs for treatment activities (T): excludes costs for before- (B) and after- (A)treatment activities. Calculated costs shown as "Not Calculated" if an estimate of treatment costs unavailable.

***For full-scale remediation projects, this identifies factors affecting actual project costs. For demonstration-scale projects, this identifies generic factors which would affect project costs for a future application using this technology.

Table 3. Remediation Case Studies - Summary of Cost Data (Continued)

Site Name, State (Technology)	Project Cost ($)*	Quantity Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment**	Key Factors Potentially Affecting Project/Technology Costs***
Other In Situ Technologies					
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH, and Other Sites (Hydraulic and Pneumatic Fracturing)	Not provided	Not provided	Not provided	$8-17/yd^3 soil treated $140/lb TCE removed	Demonstration project: Labor, capital equipment, site preparation, and residuals disposed are key factors affecting cost.
U.S. Department of Energy, SEG Facilities, TN (Frozen Soil Barrier Technology)	C - 481,427	35,694 ft^3	Not provided	$4-14/ft^3 ice formed (projected)	Demonstration project: Quantity of refrigeration and barrier thickness needed are key factors affecting cost.
U.S. Department of Energy, Multiple Sites (ResonantSonic Drilling)	Not provided	Not provided	Not provided	$208-270/ft well drilled (projected)	Demonstration project: Drilling difficulty and type of site (e.g., uncontaminated, hazardous waste, mixed waste) are key factors affecting cost.

Project Cost*
T = Costs for treatment activities, including preprocessing, capital equipment, operation, and maintenance
B = Costs for before-treatment activities, including site preparation, excavation, and sampling and analysis
A = Costs for after-treatment activities, including disposal of residuals and site restoration
C = Capital costs
O = Annual operating costs

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**Calculated based on costs for treatment activities (T): excludes costs for before- (B) and after- (A)treatment activities. Calculated costs shown as "Not Calculated" if an estimate of treatment costs unavailable.

***For full-scale remediation projects, this identifies factors affecting actual project costs. For demonstration-scale projects, this identifies generic factors which would affect project costs for a future application using this technology.

2.0 ABSTRACTS OF REMEDIATION CASE STUDIES

BIOREMEDIATION CASE STUDIES

Case Study Abstract

Land Treatment at the Burlington Northern Superfund Site, Brainerd/Baxter, Minnesota

Site Name: Burlington Northern Superfund Site	**Contaminants:** Polynuclear Aromatic Hydrocarbons (PAHs), Other Semivolatiles - Nonhalogenated - Total PAH concentrations ranged from 33,982 to 70,633 mg/kg - Individual PAH concentrations ranged up 21,319 mg/kg - Benzene extractable concentrations ranged from 66,100 to 112,500 mg/kg	**Period of Operation:** May 1986 - October 1994
Location: Brainerd/Baxter, Minnesota		**Cleanup Type:** Full-scale cleanup
Vendor: Mindy L. Salisbury Remediation Technologies, Inc. (ReTeC) 413 Waconta St., Suite 400 St. Paul, MN 55110 (612) 222-0841	**Technology:** Land Treatment - Land treatment unit (LTU) constructed with outer dimensions of 300 x 495 ft - LTU constructed in layers, over HDPE, silty sand, gravel, and clean, silty sand base - 1,100 to 1,500 yds^3 spread over LTU each year, to a depth of 6-8 inches - Operation included weekly cultivation, irrigation, lime addition, and cow manure application - Treatment conducted from May through October each year from 1986-1994 (9 "treatment seasons")	**Cleanup Authority:** CERCLA - Enforcement Decision Document Date June 4, 1986 - PRP Lead
SIC Code: 2491 B (Wood Preserving using Creosote)		**Point of Contact:** Tony Rutter USEPA Region V 77 . Jackson Boulevard Mail Code HSR-6J Chicago, IL 60604 (312) 886-8961
Waste Source: Manufacturing Process, Surface Impoundments	**Type/Quantity of Media Treated:** Soil and Sludge - 13,000 cubic yards of soil and sludge	
Purpose/Significance of Application: Full-scale application of land treatment at a creosote-contaminated site		

Regulatory Requirements/Cleanup Goals:
- Total PAHs (sum of 17 specific constituents) less than 8,632 mg/kg
- Methylene chloride extractable (MCE) hydrocarbons (a replacement for benzene extractables) less than 21,000 mg/kg
- Place a cover over the LTU if cleanup goals not met

Results:
- Cleanup goal of 8,632 mg/kg for total PAHs was met for all nine treatment seasons
- At completion of treatment, total PAH concentration ranged from 608-795 mg/kg throughout the LTU
- Cleanup goal of 21,000 mg/kg for MCE hydrocarbons was not met for any treatment season
- At completion of treatment, MCE hydrocarbon concentration ranged from 24,800-26,900 mg/kg throughout the LTU
- A cover was placed over the LTU after completion of treatment

Land Treatment at the Burlington Northern Superfund Site, Brainerd/Baxter, Minnesota (Continued)

Cost Factors:
No information on actual cost data were provided for this application

Description:
The Burlington Northern site was the location of a railroad tie treating plant that operated from 1907 to 1985. Wood preserving processes operated at the site involved pressure treatment using a heated creosote/coal tar or creosote/fuel oil mixture. Wastewater generated from the wood preserving processes was discharged to two shallow, unlined surface impoundments for disposal. In the 1980s, EPA determined that soil beneath these two surface impoundments, as well as soil in three other areas at the site (the process, drip track, and black dock areas) were contaminated. Total PAH concentrations for visibly-contaminated soils in the surface impoundments were measured as high as 70,633 mg/kg, with individual PAHs measured as high as 21,319 mg/kg. Concentrations of benzene-extractable constituents in the surface impoundment soils ranged from 66,100 to 112,500 mg/kg.

Based on a consent agreement, EPA issued an Enforcement Decision Document (a predecessor to a ROD) in June 1986, which required Burlington Northern to treat visibly-contaminated soils and sludges using on-site land treatment. The land treatment unit (LTU) used in this application had outer dimensions of approximately 300 by 495 feet (150,000 ft^2) and an area available for treatment of approximately 255 by 450 feet (115,000 ft^2). Each year from 1986 through 1994 (nine years total), between 1,100 and 1,500 cubic yards of contaminated soil and sludge were spread over the LTU to a depth of 6-8 inches. Land treatment was conducted from May through October (the "treatment season"), and included weekly cultivation, irrigation, lime addition, and cow manure application. The analytical data from the LTU at the completion of treatment indicate that the cleanup goal was met for total PAHs with the concentration of total PAHs ranging from 608 to 795 mg/kg throughout the depth of the treated soil and sludge. However, MCE hydrocarbons in the treated soil ranged from 24,800 to 26,900 mg/kg, and the cleanup goal was not met. Therefore, a cover was placed over the LTU.

MCE hydrocarbons were not treated to below the cleanup level because a "plateau effect" limited the extent of biodegradation of these constituents. However, MCE hydrocarbons are no longer typically used as a performance measure for land treatment systems. This application demonstrated that treatment efficiency for PAHs decreased with increasing number of ring structures in the PAH molecule (e.g., two-ring more efficient, four-ring less efficient). The land treatment application at Burlington Northern was PRP-lead, and no information on actual total costs or unit costs incurred is provided in the available references.

Case Study Abstract

Composting at the Dubose Oil Products Co. Superfund Site, Cantonment, Florida

Site Name: Dubose Oil Products Co. Superfund Site	**Contaminants:** Organic compounds - volatiles, halogenated; volatiles, nonhalogenated (BTEX); semivolatiles, halogenated and semivolatiles, nonhalogenated (PAHs) - Total VOC concentrations ranged from 0.022-38.27 mg/kg - Total PAH concentrations ranged from 0.578-367 mg/kg - PCP concentration ranged from 0.058-51 mg/kg	**Period of Operation:** November 1993 - September 1994
Location: Cantonment, Florida		**Cleanup Type:** Full-scale cleanup
Vendor: David Price/Garland Long Waste Abatement Technology, L.P. (WATEC) 1300 Williams Drive Marietta, GA 30066 (770) 427-1947	**Technology:** Composting - Treatment structure was 33,000 ft^2 modular building - Included systems for leachate collection, aeration, inoculum growth and application, and wastewater treatment - Ambient air was drawn down through soil pile - Operating parameters included soil oxygen and moisture contents, pH, and nutrient levels - Each batch of soil was treated to less than the cleanup goals within 14-30 days	**Cleanup Authority:** CERCLA - ROD Date 3/29/90 - PRP Lead
SIC Code: 4953 W (Waste processing facility, miscellaneous)		**Point of Contact:** Mark Fite USEPA Region 4 Atlanta Federal Center 100 Alabama St., S.W. Atlanta, GA 30303 (404) 562-8927
Waste Source: Waste Treatment Plant	**Type/Quantity of Media Treated:** Soil - 19,705 tons of soil - Lakeland loamy sand - TPH 300-600 mg/kg - Moisture content 8%	
Purpose/Significance of Application: Full-scale application of composting to treat VOC- and PAH-contaminated soil		

Regulatory Requirements/Cleanup Goals:
- Total PAHs (sum of 17 specific constituents) less than 50 mg/kg
- Total xylenes less than 1.5 mg/kg; benzene less than 10 mg/kg; TCE less than 0.05 mg/kg; DCE less than 0.07 mg/kg; and PCP less than 50 mg/kg

Results:
- Cleanup goal met for all constituents, with total PAHs in treated soil ranging from 3.3-49.9 mg/kg
- Of the 58,559 tons of soil excavated, only 19,705 tons exceeded cleanup goal and thus required treatment

Composting at the Dubose Oil Products Co. Superfund Site, Cantonment, Florida (Continued)

Cost Factors:
- Actual costs of $7,736,700 were reported by the PRP Steering Committee
- The cost for activities directly attributed to treatment was not provided separately from the total project cost, and therefore a unit cost for treatment was not calculated

Description:
The Dubose Oil Product Co. Superfund site is a former waste treatment, recycling, and disposal facility that operated from 1979 to 1981. Operations performed at Dubose included thermal treatment of waste oil, petroleum refining wastes, oil-based solvents, and wood treatment wastes; steam heating of spent iron and pickle liquors; and rock salt filtration of waste diesel fuel. During a remedial investigation (RI), soil at the site was found to be contaminated with PAHs at concentrations ranging from 0.578 to 367 mg/kg total PAH, PCP ranging from 0.058 to 51 mg/kg, and VOCs ranging from 0.022 to 38.27 mg/kg.

A Record of Decision (ROD) was signed for this site in March 1990. Composting was selected in the ROD instead of in situ biological treatment because it was identified as easier to control and more reliable, and because it was believed that monitoring would be easier to perform. The composting system used at Dubose consisted of a treatment structure, a leachate collection system, an aeration system, an inoculum growth and application system, and an on-site wastewater treatment system. Contaminated soil was treated in batches, with each batch containing from 660 to 2,310 tons of soil. For most of the batches, soil depth ranged from 4.0 to 4.25 feet. Composting activities were performed from May to November 1993, and site restoration activities were completed by August 1996.

All 359 soil grids in the compost system met the soil cleanup goals established for Dubose. For total PAHs, before-treatment concentrations ranged from 50.8 to 576.2 mg/kg, while after-treatment concentrations ranged from 3.3 to 49.9 mg/kg (average - 19 mg/kg). For PCP, before-treatment concentrations ranged from 7.67 to 160 mg/kg, while after-treatment concentrations ranged from 16.5 to 36.3 mg/kg. The primary removal mechanism identified for VOCs in this application was volatilization, while for PAHs it was bioremediation. Several lessons were learned about operation of the composting system during this application. For example, the vendor indicated that applying an inoculum mixture with a fire hose provided for adequate diffusion of soil moisture.

Case Study Abstract

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

Site Name:
Southeastern Wood Preserving Superfund Site

Location:
Canton, Mississippi

Contaminants:
Polynuclear Aromatic Hydrocarbons
- Total PAH concentrations approximately 4,000 mg/kg
- Total carcinogenic PAH concentrations ranged from approximately 1,000-2,500 mg/kg

Period of Operation:
1991-1994

Cleanup Type:
Full-scale cleanup

Vendor:
Douglas E. Jerger/Pat Woodhull
OHM Remediation Services Corp.
16406 U.S. Route 224 East
P.O. Box 551
Findlay, OH 45840
(419) 425-6175

Technology:
Slurry Phase Bioremediation
- System included a power screen, slurry mix tank, 4 bioreactors, and dewatering unit
- Bioreactors were 38 ft diameter and 24 ft high, and equipped with diffusers and a blower for aeration, and an impeller for mixing and suspension
- Each bioreactor had a 180,000 gal capacity
- 61 batches were treated, with each batch consisting of 160-180 yd^3 of material

Cleanup Authority:
CERCLA
- Action Memorandum Date 9/30/90
- Fund Lead

SIC Code:
2491 B (Wood Preserving using Creosote)

Point of Contact:
R. Donald Rigger
USEPA Region 4
345 Courtland Street, N.E.
Atlanta, GA 30365
(404) 347-3931

Waste Source:
Manufacturing Process/Surface Impoundment/Lagoon

Purpose/Significance of Application:
Full-scale application of slurry phase bioremediation to treat soil with relatively elevated levels of PAHs

Type/Quantity of Media Treated:
Soil and Sludge
- 14,140 tons (10,500 cubic yards) total
- Clay: 55%; sand: 40%; and gravel: 5%
- Various types of debris were present in the excavated materials

Regulatory Requirements/Cleanup Goals:
- Total PAHs (sum of 16 specific constituents) less than 950 mg/kg
- Benzo(a)pyrene (B(a)P)-equivalent carcinogenic PAHs less than 180 mg/kg
- Cleanup goals based on an LDR treatability variance

Results:
- Cleanup goal met for total and B(a)P-equivalent PAHs
- Average total PAH concentrations reduced from 8,545 to 634 mg/kg
- Average B(a)P-equivalent PAH concentrations reduced from 467 to 152 mg/kg

Cost Factors:
- Actual costs of $2,900,000 included treatment, design engineering, treatability, and pilot-scale testing
- Of this total, approximately $2,400,000 were for activities directly attributed to treatment
- The unit cost for activities directly attributed to treatment was $170/ton

Slurry Phase Bioremediation at the Southeastern Wood Preserving Superfund Site, Canton, Mississippi (Continued)

Description:
The Southeastern Wood site was the location of a creosote wood preserving facility that operated from 1928 to 1979, and included three unlined wastewater treatment surface impoundments. Bottom sediment sludge from the impoundments was found to contain PAHs at levels of approximately 4,000 mg/kg, and was identified as a RCRA K001-listed hazardous waste. PAH concentrations measured included acenaphthene at 705 mg/kg, naphthalene at 673 mg/kg, and benzo(a)pyrene (B(a)P) at 224 mg/kg.

A slurry phase bioremediation system was operated at Southeastern Wood from July 1991 until 1994, and consisted of a power screen, a slurry mix tank, four slurry phase bioremediation reactors (bioreactors), and a slurry dewatering unit. The bioreactors were 38 feet in diameter and 24 feet in height, and were equipped with a blower for aeration and an impeller for mixing and keeping the slurry in suspension. The bioreactors were operated on a batch basis, and each batch was monitored during treatment to evaluate performance with respect to the cleanup goals. Treatment performance data are available for 13 of the 61 bioreactor batches, and show that the average total PAH concentration was reduced from 8,545 to 634 mg/kg, which corresponds to a treatment efficiency of 93 percent. The average B(a)P-equivalent concentration was reduced from 467 to 152 mg/kg, or 67 percent.

This application showed that treatment efficiency was greater for PAH constituents with 2-4 rings, and lower for PAHs with 5-6 rings. The design of the treatment process was modified significantly from the original plans, including addition of a desanding process. Operating problems identified in this application included foam production in the bioreactors, and achievability of LDR treatment standards (which lead to a need for a treatability variance).

Case Study Abstract

Cost Report: Windrow Composting to Treat Explosives-Contaminated Soils at Umatilla Army Depot Activity (UMDA)

Site Name: Umatilla Army Depot Activity (UMDA)	**Contaminants:** Explosives - Primary soil contaminants include 2,4,6-Trinitrotoluene (TNT); Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX); Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX); and 2,4,6-Trinitrophenylmethylnitramine (Tetryl) - TNT and RDX soil concentrations ranged from 100 to 2,000 ppm; and HMX from <1 to 100 ppm - Contamination present in top 6 ft of soil	**Period of Operation:** March 1994 - September 1996 (anticipated end date)
Location: Hermiston, Oregon		**Cleanup Type:** Full-scale remediation
Vendor: Wilder Construction Co. (Phase I) Bioremediation Services, Inc. (Phase II)	**Technology:** Composting (Windrow) - Soil excavated and stored on site (Phase I) - Soil treated inside 200 x 90 ft structure (Phase II) - Moisture content maintained at 30-35% - Turning frequency was once every 24 hrs for first 5 days followed by less frequent turning on subsequent days - Composting batches required approximately 22 days to reach cleanup goals - Full-scale treatment based on 3 trial tests	**Cleanup Authority:** CERCLA - ROD Date: September 1992
SIC Code: 9711 (National Security)		**Point of Contact:** Remedial Project Manager Umatilla Army Depot Activity Hermiston, OR
Waste Source: Surface Impoundment/Lagoon	**Type/Quantity of Media Treated:** Soil - 10,969 cubic yards (13 windrows with 810 cubic yards each and 1 windrow with 439 cubic yards) - Predominantly Quincy fine sand and Quincy loamy fine sand - Soil pH gradually increased from 7 (at ground surface) to 8.5 at 5 ft below ground surface	
Purpose/Significance of Application: First full-scale application of windrow composting to biodegrade explosives-contaminated soils		
Regulatory Requirements/Cleanup Goals: - Concentrations of explosives in soil of less than 30 ppm for each of target compounds - TNT and RDX		
Results: - Windrow composting generally reduced the levels of target explosives to below the cleanup goals - Average concentrations prior to composting were 190 ppm for TNT and 227 ppm for RDX - 27 x 30 cu. yd. grids sampled in each batch - Through 11 batches, only 2 of almost 300 grids did not meet cleanup goal after initial phase of treatment		

Cost Report: Windrow Composting to Treat Explosives-Contaminated Soils at Umatilla Army Depot Activity (UMDA) (Continued)

Cost Factors:
- Actual total project cost of $5,131,106, corresponding to a unit cost of $346 per ton from mobilization to demobilization
- Phase I cost $1,320,162 (soil excavation and storage)
- Phase II cost $3,810,944 (soil treatment)
- Costs specific to biological treatment ($1,989,454) correspond to unit cost of $181/cubic yard soil treated

Description:
From approximately 1955 to 1965, the UMDA operated a munitions washout facility in Hermiston, Oregon, where hot water and steam were used to remove explosives from munitions casings. About 85 million gallons of heavily-contaminated wash water were discharged to two settling lagoons at the site. The underlying soils and groundwater were determined to be contaminated with explosive compounds, primarily TNT, RDX, and HMX, and the site was placed on the NPL in 1987.

Windrow composting was used for a full-scale remediation at UMDA, with treatment taking place from July 1995 to September 1996 (anticipated completion date per September 1996 report). A total of 10,969 yd^3 of contaminated soil were treated at UMDA, in 14 batches. Analytical results indicated that average concentrations were reduced from 190 to <30 ppm for TNT, and from 227 to <30 ppm for RDX. Through 11 batches, only two of almost 300 grids did not meet the cleanup goal (30 ppm) after an initial phase of treatment.

Detailed information on actual costs for this application are provided in the report. Actual costs are shown according to an interagency Remedial Action-Work Breakdown Structure (RA-WBS). Factors affecting costs that were identified for this application included climate, soil characteristics, and amendment availability and cost. For example, the semi-arid cool climate and sparse vegetation at UMDA contributed to fairly low preparatory site work cost. Amendment availability and cost are significant factors for composting and are driven by the proximity, seasonality, quality, and consistency of the materials to be used. At UMDA, the majority of the amendments were readily available in the Umatilla area.

Case Study Abstract

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

Site Name:
U.S. Department of Energy (DOE), Savannah River Site (SRS), M Area Process Sewer/Integrated Demonstration Site

Location:
Aiken, South Carolina

Contaminants:
Chlorinated Aliphatics
- Trichloroethene (TCE) and tetrachloroethene (PCE)
- TCE concentrations in the ground water ranged from 10 to 1031 μg/L, and PCE from 3 to 124 μg/L
- TCE concentrations in the sediments ranged from 0.67 to 6.29 mg/kg, and PCE from 0.44 to 1.05 mg/kg.

Period of Operation:
February 1992 to April 1993

Cleanup Type:
Field demonstration

Technical Information:
Terry Hazen and Brian Looney, Prin. Inv., WSRC, (803) 725-6413, (803) 725-3692
Caroline Teelon, (Licensing Information), WSRC, (803) 725-5540

SIC Code:
9711 (National Security)
3355 (Aluminum Forming)
3471 (Metal Finishing)

Technology:
In Situ Bioremediation (ISB)
- Combines gaseous injection of air and nutrients (N, P, CH4) into ground water with soil vacuum extraction
- Provides for sparging/biodegradation of VOCs in the ground water
- Uses horizontal wells to provide more effective access to subsurface contamination
- Horizontal wells installed at 176 ft below ground surface (bgs) (saturated zone - used for injection) and 75 ft bgs (vadose zone - used for extraction)

Cleanup Authority:
State: Air discharge and underground injection control (UIC) permits for the SRS are in place with the South Carolina Department of Health and Environmental Control (SCDHEC).

Points of Contact:
Kurt Gerdes, DOE, (301) 903-7289
Jim Wright, DOE, (803) 725-5608

Waste Source:
Surface impoundment (unlined settling basin)

Purpose/Significance of Application:
ISB combines biodegradation (sparging and biostimulation) with SVE to remediate both soil and ground water contaminated with VOCs

Type/Quantity of Media Treated:
Soil (sediment) and Ground Water
- Water table located at 120 ft bgs
- Vadose zone well radius of influence estimated to be greater than 200 ft
- Saturated zone well influence extended as far as 100 ft from well
- Vadose zone soils consists of sand, silt, clay, and gravel, with layers ranging up to 18% silt and clay
- Saturated zones consist of several layers of sand with silt and clay beds

Regulatory Requirements/Cleanup Goals:
- The demonstration was covered by permits issued by the SCDHEC, including an air quality permit and a UIC permit (because of the addition of methane and nutrients).
- Groundwater protection standards of 5 ppb for TCE and PCE, and 200 ppb for TCA, were identified for Area M

In Situ Bioremediation Using Horizontal Wells, U.S. Department of Energy, M Area, Savannah River Site, Aiken, South Carolina (Continued)

Results:
- Almost 17,000 lbs of VOCs were removed or degraded over 384 days of operation (12,096 lbs extracted and 4,838 lbs biodegraded)
- Mass balance data showed that bioremediation destroyed 40% more VOCs than simple air sparging
- ISB reduced VOC concentrations in the ground water below the 5 ppb cleanup goals for TCE and PCE; overall groundwater concentrations were reduced by up to 95%
- VOC concentrations in most sediments were nondetectable; soil gas concentrations decreased by more than 99%

Cost Factors:
- No information is provided on the capital or operating costs for the ISB demonstration at SRS
- An analysis of capital and operating costs for an ISB application was made by LANL in a comparison with conventional pump and treat with SVE
- The LANL analysis showed that ISB had capital costs approximately 30% greater than PT/SVE, operating costs 10% lower, and would require 3 yrs instead of 10 yrs to remediate the demonstration site

Description:
From 1958 to 1985, Savannah River Area M conducted manufacturing operations including aluminum forming and metal finishing. Process wastewater from these operations containing solvents (TCE, PCE, and TCA) was discharged to an unlined settling basin at Savannah River, which lead to contamination of ground water and vadose zone soils. Full-scale treatment of groundwater began in 1985. Treatment of vadose and saturated zones has been the subject of several demonstrations (e.g., in situ air stripping), including this investigation of the technical and economic feasibility of in situ bioremediation (ISB) technology.

ISB combines gaseous injection of air and nutrients (N, P, CH4) into ground water with soil vacuum extraction technology. This provides for sparging and biodegradation of VOCs in the ground water, and extraction of VOCs from the vadose zone. At SRS, two horizontal wells were used to provide more effective access to subsurface contamination. Horizontal wells were installed at 176 ft bgs (in the saturated zone - used for injection) and 75 ft bgs (in the vadose zone - used for extraction).

Almost 17,000 lbs of VOCs were removed or degraded at SRS over 384 days of ISB operation. This total consists of 12,096 lbs of VOCs extracted and 4,838 lbs biodegraded. Mass balance data showed that bioremediation destroyed 40% more VOCs than simple air sparging, and that it reduced VOC concentrations in the ground water below the 5 ppb cleanup goals for TCE and PCE. Overall TCE and PCE groundwater concentrations were reduced by up to 95%. In addition, VOC concentrations in most sediments were nondetectable, with soil gas concentrations decreased by more than 99%.

Case Study Abstract

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

Site Name:
U.S. Department of Energy (DOE), Paducah Gaseous Diffusion Plant Cylinder Drop Test Area

Location:
Paducah, Kentucky

Contaminants:
Trichloroethene (TCE)
- TCE concentrations in clay soil ranged from 1 ppb to 1760 ppm
- Average TCE concentration was 83.2
- Highest TCE concentrations (200 - 300 ppm) found 12-16 ft below surface

Period of Operation:
January - May 1995

Cleanup Type:
Field demonstration

Technical Information:
Sa V. Ho, Monsanto, (314) 694-5179
Steven C. Meyer, Monsanto, (314) 275-5946
Joseph J. Salvo, GE, (518) 387-6123
Stephen H. Shoemaker, DuPont, (713) 586-2513

SIC Code:
Not Available

Technology:
Integrated in situ technology
- patented technology developed by an industrial consortium consisting of Monsanto, GE, and DuPont
- combines electroosmosis, biodegradation, and physicochemical treatment processes
- electrodes energized by direct current cause water and soluble contaminants to move through treatment layers
- treatment zones decompose or adsorb contaminants
- water collected at the cathode is recycled to the anode for acid-base neutralization

Cleanup Authority:
EPA and State of Kentucky

Points of Contact:
Skip Chamberlain, DOE, (301) 903-7248
Dave Biancosino, DOE, (301) 903-7961
Jim Wright, DOE, (803) 725-5608
Kelly Pearce, DOE, (304) 285-5424

Waste Source:
Not Available

Purpose/Significance of Application:
Lasagna™ is an in situ technology suited to sites with low permeability soils that combines several technologies to remediate soil and soil pore water contaminated with soluble organic compounds

Type/Quantity of Media Treated:
Soil and soil pore water
- 4 ft layer of gravel and clay overlaying 40 ft layer of sandy clay loam with interbedded sand layers
- low organic content
- 15 ft wide x 10 ft across x 15 ft deep

Regulatory Requirements/Cleanup Goals:
- A cleanup standard for TCE in soil was set at 5.6 ppm.
- No air permits or Underground Injection permits were needed.
- The demonstration was granted a categorical exclusion under the NEPA.

Lasagna™ Soil Remediation at the U.S. Department of Energy Cylinder Drop Test Area, Paducah Gaseous Diffusion Plant, Paducah, Kentucky (Continued)

Results:
- Treatment reduced TCE concentrations in test zone on average from 72.6 to 1.1 ppm (a 98% reduction)
- An electroosmosis flow rate of 4 L/hr was achieved, and 3 pore volumes of water were transported during a 4-month operating period
- In probable DNAPL locations, TCE was reduced to less than 1 ppm, except for one deep location near an untreated zone that was reduced to 17.4 ppm (diffusion from untreated deep zones suspected)
- Results from the field demonstration were used to develop plans for expanded treatment at Paducah

Cost Factors:
- No data are provided on the capital or operating costs for the field demonstration
- DuPont analyzed the costs for using Lasagna™ to treat TCE-contaminated clayey soil, and estimated that costs would range from \$40 to 90/yd^3 of soil for a 1-acre site, ranging from 1-3 years for remediation
- Major cost elements include electrode construction; other factors include electrode spacing, placement of electrodes and treatment zones, soil properties, depth of contamination, required purge water volume, cleanup time, and cost of electrical power
- DuPont benchmarked unit costs for Lasagna™ compared with other in situ technologies which required more than 30 years to remediate a site (in situ treatment zones using iron filings, pump and treat, in situ aerobic biological treatment, and surfactant flushing) and determined that Lasagna™ is within the range of unit costs for these technologies (\$25-75/yd^3)

Description:
Lasagna™ is an in situ technology that combines electroosmosis, biodegradation, and physicochemical treatment processes to treat soil and soil pore water contaminated with soluble organic compounds. The technology was developed by an industrial consortium consisting of Monsanto, GE, and DuPont and patents for the technology and the trademark have been granted to Monsanto. The technology is suited for sites with low permeability soils. The process uses electrokinetics to move contaminants in soil pore water into treatment zones where the contaminants can be captured or decomposed.

At the Paducah Gaseous Diffusion Plant, Lasagna™ was demonstrated on a clayey soil contaminated with TCE, with an average concentration of 83 ppm. Treatment reduced TCE concentrations in a test zone from on average 72.6 to 1.1 ppm (a 98% reduction). An electroosmosis flow rate of 4 L/hr was achieved, and 3 pore volumes of water were transported during a 4-month operating period. Results from the field demonstration were used to develop plans for expanded treatment at Paducah (scheduled for June 1996, per report dated April 1996).

3.0 VITRIFICATION CASE STUDIES

Case Study Abstract

In Situ Vitrification at the Parsons Chemical/ETM Enterprises Superfund Site, Grand Ledge, Michigan

NOTE: This report is the final version of the EPA Cost and Performance Report for this application, and supersedes the interim version of this report published in Volume 4 of this series in March 1995. This final version reflects the most recent sampling of the vitrified material.

Site Name: Parsons Chemical/ETM Enterprises Superfund Site	**Contaminants:** Pesticides, heavy metals, and dioxin - Pesticide concentrations ranged up to 340,000 μg/kg (4,4'-DDT) - Zinc concentration 150,000 μg/kg - 2,3,7,8-TCDD concentration 1.13 μg/kg	**Period of Operation:** May 1993 to May 1994
Location: Grand Ledge, Michigan		**Cleanup Type:** Full-scale cleanup
Vendor: James E. Hansen Geosafe Corporation 2950 George Washington Way Richland, WA 99352 (509) 375-0710	**Technology:** In Situ Vitrification - 9 melt cells, each 26x26 ft square and 16 ft deep - Air emissions controls included an off-gas collection hood, quencher, water scrubber, and thermal oxidizer - 8 melts required to vitrify the soil - Melts ranged from 10 to 19.5 days - Melts required approximately one year to cool sufficiently to sample	**Cleanup Authority:** CERCLA - Action Memorandum Date 9/21/90 - Fund Lead
SIC Code: 2879 (Agricultural Chemicals, NEC)		**Point of Contact:** Len Zintak USEPA Region 5 77 West Jackson Boulevard Chicago, IL 60604-3507 (312) 886-4246
Waste Source: Manufacturing Process	**Type/Quantity of Media Treated:** Soil and sediment - 3,000 cubic yards (5,400 tons) - Silty clay	
Purpose/Significance of Application: First application of ISV at a Superfund site		

Regulatory Requirements/Cleanup Goals:
- Cleanup requirements identified for both soil and off-gasses
- Soil cleanup requirements were as follows: chlordane: 1 mg/kg; 4,4"-DDT: 4 mg/kg; dieldrin: 0.08 mg/kg; and mercury: 12 mg/kg

Results:
- Confirmation coring samples indicated that vitrified materials met soil cleanup requirements for pesticides and mercury
- Pesticides and mercury in vitrified material and soil beneath vitrified material were below detection limits
- Stack gas emissions met off-gas cleanup requirements

Cost Factors:
- Contractor's costs were specified in terms of a ceiling of $1,763,000
- Of this total, approximately $800,000 were for activities directly attributed to treatment
- The unit cost for activities directly attributed to treatment was $267/yd^3

In Situ Vitrification at the Parsons Chemical/ETM Enterprises, Superfund Site, Grand Ledge, Michigan (Continued)

Description:
The Parsons site is a former agricultural chemicals mixing, manufacturing, and packaging facility. Soils and sediments at the Parsons site were contaminated with pesticides, heavy metals, and dioxins. ISV treatment of approximately 3,000 yd^3 of contaminated soils and sediments at the Parsons site, consisting of eight melts, was performed from May 1993 to May 1994. This was notable for being the first full-scale application of ISV treatment at a Superfund site.

Confirmation coring sampling could not be performed until after the ISV melt had cooled, approximately one year after treatment was completed. Three corings, or drill holes, were performed in locations selected to represent the ares with potential residual contamination. The confirmation coring sampling results indicated that the vitrified material in all three drill holes had mercury and pesticide concentrations below detection limits, and therefore that the vitrified material met the cleanup goals for this application. Also, analytical data for volatiles and semivolatiles in the containment soil beneath the three drill holes were reported as below detection limits, indicating that volatiles and semivolatiles were not present in the soil beneath the vitrified material.

This application demonstrated that final sampling of vitrified material needs to allow adequate time for the melt to cool (e.g., one year). In addition, the vendor identified several operational issues (e.g., decomposition of particle board forms, irregular melt shapes) during treatment of the first few cells at Parsons. The cleanup contractor's cost ceiling for the ISV treatment application at Parsons was $1,763,000, including $800,000 for vitrification, which corresponds to $267 per cubic yard of soil treated.

Case Study Abstract

In Situ Vitrification, U.S. Department of Energy, Hanford Site, Richland, Washington; Oak Ridge National Laboratory WAG 7, Oak Ridge, Tennessee; and Various Commercial Sites

Site Name:
1. U.S. Department of Energy (DOE), Hanford Site
2. Oak Ridge National Laboratory WAG 7
Various commercial sites (e.g., Parsons, Wasatch)

Contaminants:
Parsons: pesticides (chlordane, dieldrin, 4,4-DDT), metals (As, Pb, Hg)
ORNL: Radioactive elements (Ce^{137})
Wasatch: dioxin/furan, pentachlorophenol, pesticides, VOCs, SVOCs
Private Superfund site: PCBs

Period of Operation:
Information not provided

Location:
1. Richland, Washington
2. Oak Ridge, Tennessee
Commercial sites - various

Cleanup Type:
Full-scale remediation (Parsons, Wasatch)
Field demonstration (e.g., ORNL)

Technical Information:
Craig Timmerman, Geosafe Corp., (509) 375-0710

Technology:
In Situ Vitrification (ISV)
- Patented process that destroys organics and some inorganics by pyrolysis
- Uses electricity as energy source
- Remaining contaminants (heavy metals and radionuclides) are incorporated into product; product has significantly reduced leachability
- Vitrified material has 20-50% less volume than original material
- Hood used to contain and collect off-gasses from melt

Cleanup Authority:
- Information not provided about authorities for specific remediations and demonstrations
- Detailed regulatory analysis of ISV provided by CERCLA criteria

SIC Code:
9711 (National Security)
Commercial sites - Information not provided
Others - Information not provided

Points of Contact:
J. Hansen, Geosafe, (509) 375-0710
Jim Wright, DOE, (803) 725-5608
B. Spalding, ORNL, (423) 574-7265

Waste Source:
Wasatch - Other (concrete evaporation pond)
Others - Information not provided

Type/Quantity of Media Treated:
Soil, Sludge, and Debris
- Parsons: 4800 tons
- Wasatch: 5600 tons
- Private Superfund site: 3100 tons

Purpose/Significance of Application:
Full-scale and field demonstrations of ISV for variety of media types and variety of contaminants

Regulatory Requirements/Cleanup Goals:
- Parsons: regulatory limits for Hg, chlordane, dieldrin, and 4,4-DDT
- Others - information not provided

In Situ Vitrification, U.S. Department of Energy, Hanford Site, Richland, Washington; Oak Ridge National Laboratory WAG 7, Oak Ridge, Tennessee; and Various Commercial Sites (Continued)

Results:
- Parsons: contamination reduced to below detection limits (ND) for most constituents
- Wasatch: molten product dip samples and surrounding berm post-ISV samples mostly ND
- ORNL treatability test had a "melt expulsion event (MEE)" where excess water vapor generation upset the melt and caused overheating of the off-gas collection hood
- Superfund site in Washington State showed DRE for PCBs of greater than 99.9999%

Cost Factors:
- Vitrification operations $375-425/ton
- Ancillary costs: treatability/pilot testing - $50-150K; mobilization - $150-200K; and demobilization - $150-200K
- No information is provided on the capital or operating costs for specific full-scale or demonstration projects

Description:
In situ vitrification (ISV) has been used in three large-scale commercial remediations in the United States and in several demonstrations. The commercial remediations were conducted at the Parsons Chemical Superfund site (see separate report on Parsons); a Superfund site in Washington State; and at the Wasatch Chemical site. A demonstration of ISV was conducted at ORNL WAG 7 on Cs^{137}-contaminated material, where a melt expulsion event occurred .

ISV simultaneously treats mixtures of waste types, contaminated with organic and inorganic compounds. ISV has been demonstrated at sites contaminated with hazardous and mixed wastes, and achieves volume reductions ranging from 20-50%. Metals and radioactive elements are bound tightly within the vitrified product. Full-scale remediation at Parsons met the regulatory limits for chlordane, dieldrin, 4,4-DDT, and mercury. Full-scale remediation at Wasatch achieved ND for 12 constituents in the molten product dip samples. A TSCA demonstration at a Superfund site in Washington State showed destruction and removal efficiency (DRE) for PCBs of greater than 99.9999%. At the ORNL WAG 7 demonstration, a need was identified to take additional precautions when dealing with sites containing large amounts of free water.

Site requirements for ISV, as identified by the vendor, are a function of: (1) the size and layout for equipment used in the process; (2) the staging area requirements for treatment cell construction; and (3) the area needed for maneuvering and operating equipment, excavating soils, and preparing treatment cells. In addition, the properties for fusion, melt temperature, and viscosity are determined by the overall oxide composition of the soil.

4.0 SOIL VAPOR EXTRACTION CASE STUDIES

Case Study Abstract

Soil Vapor Extraction at the Basket Creek Surface Impoundment Site, Douglasville, Georgia

Site Name:
Basket Creek Surface Impoundment Site

Location:
Douglasville, Georgia

Contaminants:
Organic Compounds (Volatiles - Halogenated: trichloroethene (TCE); and Volatiles - Nonhalogenated: toluene, methyl isobutyl ketone (MIBK), and methyl ethyl ketone (MEK)) and Inorganic Compounds (Heavy Metals: lead and mercury)
- Toluene: BDL-220,000 mg/kg
- MIBK: BDL-66,000 mg/kg
- MEK: BDL-23,000 mg/kg

Period of Operation:
November 1992 to April 1993

Cleanup Type:
Full-scale cleanup

Vendor:
Mark Rigatti
OHM Remediation Services Corp.
5335 Triangle Parkway, Suite 450
Norcross, GA 30092
(770) 453-7630

SIC Code:
4953 W (Refuse Systems - waste processing facility, miscellaneous)

Technology:
Soil Vapor Extraction (ex situ)
- In situ SVE was not used because of low soil permeability
- Soil was excavated on a grid basis
- 48 grids were excavated, each 10x10 ft square
- Treatment was conducted in metal building 60 ft wide by 120 ft long by 26 ft tall
- System included shaker (power) screen, 17 horizontal vapor extraction wells, 3 vacuum pumps, a baghouse, and a thermal oxidizer

Cleanup Authority:
CERCLA
- Action Memorandum Date 4/11/91
- Fund Lead

Point of Contact:
R. Donald Rigger
USEPA Region 4
345 Courtland Street, N.E.
Atlanta, GA 30365
(404) 347-3931

Waste Source:
Surface Impoundment/Lagoon

Purpose/Significance of Application:
Ex situ SVE application on low-permeability soil contaminated with organic and inorganic constituents.

Type/Quantity of Media Treated:
Soil
- 1,600 cubic yards (2,400 tons)
- Particle size distribution: clay - 16.4%; silt - 34.4%; sand - 40.8%; and gravel - 8.4%
- Air permeability: 1.5×10^{-7} cm/sec

Regulatory Requirements/Cleanup Goals:
- Soil treatment targets identified for 4 VOCs, lead, mercury, and total HOCs
- Targets for VOCs and metals set at TC regulatory levels

Results:
- Soil treatment targets met for all 14 sampling grids after 6 months of treatment
- TCLP results were as follows: TCE - <0.1 mg/L; PCE - < 0. 3 mg/L; benzene - <0.03 mg/L; MEK - < 2.0 mg/L; lead < 2.0 mg/L; and mercury - all ND
- 72,000 lbs of total VOCs recovered in this application

Soil Vapor Extraction at the Basket Creek Surface Impoundment Site, Douglasville, Georgia (Continued)

Cost Factors:
- Actual costs of $2,200,000 were expended, including $1,300,000 for before-treatment activities, $660,000 for activities directly attributed to treatment, and $220,000 for after-treatment activities
- The unit cost for activities directly attributed to treatment was $413/yd^3 of soil treated ($275/ton), and $9.20/lb of VOC removed

Description:
Basket Creek was used in the 1960s for illegal disposal of liquid refinery and other hazardous wastes. In 1991, soil at the site was identified as a RCRA hazardous waste exhibiting the Toxicity Characteristic (TC) for lead, MEK, and TCE. Soil samples collected in March 1990, May 1991, and January 1992 showed the following concentrations in a total waste analysis: TCE - below detection limit (BDL) to 8,600 mg/kg; PCE - BDL to 2,700 mg/kg; toluene - BDL to 220,000 mg/kg; xylenes - BDL to 7,300 mg/kg; MEK - BDL to 23,000 mg/kg; and MIBK - BDL to 66,000 mg/kg.

An action memorandum for Basket Creek was signed on April 11, 1991 and specified soil treatment targets for TCE, PCE, benzene, MEK, lead, mercury, and total halogenated organic compounds (HOCs). An ex situ SVE system was used at Basket Creek, consisting of a 7,200 ft^2 containment building, a shaker (power) screen, 17 vapor extraction wells, vacuum pumps, a baghouse, an induced draft blower, and a thermal oxidizer. Excavation, screening, and vapor extraction all took place inside the containment building. The system was run from November 1992 to February 1993, and again from March to April 1993, for a total of 6 months of operation.

Analytical data indicated that the soil treatment targets were met for all contaminants after the six month treatment period. Total VOCs in the treated soil ranged from 0.142 to 1570.7 mg/kg, and approximately 72,000 lbs of total VOCs were recovered from the soil. Toluene was the largest quantity VOC recovered, accounting for approximately 80% of the total VOCs recovered, and MIBK was the second largest quantity, accounting for 11%. Ex situ SVE was selected for this application after in situ SVE was ruled out because of the low permeability of the contaminated soil. Excavation of soil was performed within an enclosure to control emissions. Because of space constraints, this resulted in the excavation taking a much longer time (3 months) than would have been required were the excavation to have been done outside (a few days).

Case Study Abstract

Soil Vapor Extraction at the Sacramento Army Depot Superfund Site, Burn Pits Operable Unit, Sacramento, California

Site Name:
Sacramento Army Depot Superfund Site, Burn Pits Operable Unit

Location:
Sacramento, California

Contaminants:
Organic Compounds; Volatiles-Halogenated
- Trichloroethene (TCE), tetrachloroethene (PCE), and 1,2-dichloroethene (DCE) each less than 0.01 mg/kg

Period of Operation:
May 1994 - September 1995

Cleanup Type:
Full-scale cleanup

Vendor:
Ashok Gopinath
OHM Remediation Services Corp.
5731 W. Las Positas Blvd.
Pleasanton, CA 94588
(510) 227-1100

Technology:
Soil Vapor Extraction
- System was OHM's patented Fluid Injection-Vacuum Extraction (FIVE) technology
- Included 10 shallow extraction/injection wells, 12 deep wells, 1 horizontal well, HEPA filters, and 2 trains of GAC units
- Shallow wells screened 10-25 ft below ground surface (bgs)
- Deep wells screened 50-80 and 17-47 ft bgs
- Some wells operated as injection wells and others as extraction wells

Cleanup Authority:
CERCLA
- Record of Decision Date 2/26/93
- U.S. Army Lead

SIC Code:
3471: Electroplating, Plating, Polishing, Anodizing, and Coloring
3479: Coating, Engraving, and Allied Services, Not Elsewhere Classified

Point of Contact:
Marlin Mezquita
USEPA Region 9
75 Hawthorne Street
San Francisco, CA 94105
(415) 744-2393

Waste Source:
Disposal Pit; Incineration Residuals Handling

Purpose/Significance of Application:
Full-scale application combining fluid injection and vacuum extraction wells in a complex subsurface environment.

Type/Quantity of Media Treated:
Soil
- 247,900 cubic yards
- Subsurface consists of interbedded sands, silts, and clays, with some coarse gravels
- Six facies identified during site investigation

Regulatory Requirements/Cleanup Goals:
- Soil cleanup standards for TCE, PCE, and DCE of 0.005 mg/kg
- Air emission limits identified for TCE, PCE, and DCE

Results:
- Soil cleanup goals met within 14 months of system operation
- Concentrations in treated soil were: TCE - 0.0021 mg/kg; PCE - 0.0013 mg/kg; and DCE - 0.0027 mg/kg
- Approximately 138 lbs of TCE, PCE, and DCE extracted

Cost Factors:
- Actual costs of $865,873 included $195,000 for before-treatment activities (drilling, soil gas survey, confirmatory borings, and chemical testing), and $670,500 for activities directly attributed to treatment (design, mobilization, construction, start-up/testing/permitting, SVE operations and maintenance, and demobilization)
- The unit cost for activities directly attributed to treatment was $2.70/yd^3 of soil treated, and $4,858/lb of VOC removed

Soil Vapor Extraction at the Sacramento Army Depot Superfund Site, Burn Pits Operable Unit, Sacramento, California (Continued)

Description:
The Burn Pits Operable Unit at SAAD was the location of two rectangular trenches constructed in the late 1950s and used intermittently as incineration pits until 1966. Materials reportedly buried and/or burned in the pits included plating shop wastes, oil and grease, batteries, and construction debris. Remedial investigations conducted from 1990 to 1993 showed average soil contaminant concentrations for TCE ranging from 0.0029 to 0.0069 mg/kg, PCE from 0.0029 to 0.0079 mg/kg, and DCE from 0.0038 to 0.0055 mg/kg. In addition, the Army's basewide contractor estimated the total mass of selected contaminants in the operable unit as follows: TCE - 22.3 lbs; PCE - 7.1 lbs; and DCE - 39.3 lbs.

A Record of Decision (ROD) addressing the Burn Pits O.U. was signed in March 1993. OHM's patented fluid injection/vapor extraction (FIVE) system was used to remediate the Burn Pits O.U. In the FIVE technology, pressurized air is injected into vadose zone soils to produce relatively larger subsurface pressure gradients and higher flow rates of extracted vapors than would be achieved solely with using vapor extraction technology. The vendor stated that this system "enhanced subsurface volatilization and shortened the period of remediation," however, no data were provided to support this statement. The FIVE system used at the SAAD Burn Pits consisted of 10 shallow extraction/injection wells, 12 deep extraction/injection wells, 1 horizontal extraction/injection well, air injection piping, vapor monitoring wells, liquid/vapor separators, high efficiency particulate filters, vapor phase granular activated carbon, and positive displacement blowers. The wells were screened up to 80 feet below ground surface.

Confirmatory soil borings showed that the average concentrations for each of the three target contaminants was less than the cleanup standards set in the ROD. TCE was reduced to an average concentration of 0.0021 mg/kg, PCE to 0.0013 mg/kg, and DCE to 0.0027 mg/kg. Approximately 138 lbs of TCE, PCE, and DCE were extracted during this application, or roughly two times as much VOCs as originally estimated to be present at the operable unit. Possible reasons for the discrepancy between the original estimate and the actual amount recovered identified by the treatment vendor include inaccuracies in the original estimate and for 1,2-DCE, a reductive dehalogenation mechanism that occurred in situ. According to the vendor, the use of the FIVE technology "enhanced subsurface volatilization and shortened the period of remediation"; however, no additional information comparing this technology to other SVE systems was provided.

Case Study Abstract

Soil Vapor Extraction at the Sand Creek Industrial Superfund Site, Operable Unit No. 1, Commerce City, Colorado

Site Name:
Sand Creek Industrial Superfund Site, Operable Unit No. 1

Location:
Commerce City, Colorado

Contaminants:
Volatiles - Halogenated: chloroform, methylene chloride, tetrachloroethene (PCE), and trichloroethene (TCE); Volatiles - Nonhalogenated: TPH
- Maximum soil concentrations: chloroform - 0.820 mg/kg; methylene chloride - 5.8 mg/kg; TCE - 0.087 mg/kg; and PCE - 9.34 mg/kg

Period of Operation:
September 24, 1993 - April 27, 1994

Cleanup Type:
Full-scale cleanup

Vendor:
Christopher Strzempka
Project Technical Mgr. for OU-1
OHM Remediation Services Corp.
16406 U.S. Route 224 East
Findlay, OH 45840
(800) 537-9540

Technology:
Soil Vapor Extraction
- System was OHM's patented Fluid Injection-Vacuum Extraction (FIVE) technology
- Included 31 vertical wells and 1 horizontal well, and catalytic oxidizer
- Wells screened 3-32.5 ft below ground surface (bgs)
- Some wells operated as injection wells and others as extraction wells

Cleanup Authority:
CERCLA
- Action Memorandum Date 9/29/89
- Federal Lead/Fund Financed

SIC Code:
2879 (Pesticides and Agricultural Chemicals, NEC)
2911 (Petroleum Refining)

Point of Contact:
Erna Waterman, 8 EPR-SR
USEPA Region VIII
999 18th Street, Suite 500
Denver, CO 80202-2466
(303) 312-6762

Waste Source:
Manufacturing Process

Purpose/Significance of Application:
Full-scale application combining fluid injection and vacuum extraction wells to treat VOC-contaminated soil.

Type/Quantity of Media Treated:
Soil
- Estimates of quantity treated ranged from 31,440 - 52,920 yd^3
- Sandy loams, loamy sands
- Silt and clay - 19.99-24.71%
- LNAPL plume also identified at site

Regulatory Requirements/Cleanup Goals:
- Soil cleanup goals specified for 4 VOCs as follows: chloroform - 0.165 mg/kg; methylene chloride - 0.075 mg/kg; TCE - 0.285 mg/kg; and PCE - 1.095 mg/kg

Results:
- Soil cleanup goals met within 6 months of system operation
- Maximum concentrations in treated soil were: chloroform - 0.0099 mg/kg; methylene chloride - ND; TCE - 0.10 mg/kg; and PCE - 0.28 mg/kg
- Approximately 3,250 lbs of chloroform, methylene chloride, TCE, and PCE extracted (primarily PCE)
- Approximately 176,500 lbs of total VOCs extracted

Soil Vapor Extraction at the Sand Creek Industrial Superfund Site, Operable Unit No. 1, Commerce City, Colorado (Continued)

Cost Factors:

- Approximately $2,140,000 were expended for this application, including $81,231 for before-treatment activities, and $2,058,564 for activities directly attributed to treatment
- The unit cost for activities directly attributed to treatment was $39-65/yd^3 of soil treated, and $11.70/lb of VOC removed
- EPA's decision to revise air emissions control equipment from activated carbon with off-site regeneration to catalytic oxidation resulted in a significant cost savings to the government

Description:

The Sand Creek O.U. 1 site was the location of pesticide manufacturing companies in the 1960s and 1970s, and prior to that, by a petroleum refinery. The pesticide manufacturing companies had two fires in the period from 1968-1977, and were reported to have unsatisfactory waste management practices. Remedial investigations conducted from 1984 to 1988 showed three subareas of soil contamination at Sand Creek O.U. 1 with the following maximum soil concentrations of halogenated VOCs: chloroform - 0.820 mg/kg, methylene chloride - 5.8 mg/kg, TCE - 0.087 mg/kg, and PCE - 9.34 mg/kg. Based on these concentrations, EPA estimated the total mass of the four target contaminants in the operable unit as 684 pounds.

A Record of Decision (ROD) addressing Sand Creek O.U. 1 was signed in September 1989 and an Explanation of Significant Differences (ESD) modifying the 1989 ROD was issued in September 1993. OHM's patented fluid injection/vapor extraction (FIVE) system was used to remediate O.U. 1. In the FIVE technology, pressurized air is injected into vadose zone soils to produce relatively larger subsurface pressure gradients and higher flow rates of extracted vapors than would be achieved solely with using vapor extraction technology. The FIVE system used at O.U. 1 consisted of 32 extraction/injection wells (31 vertical, 1 horizontal), three positive displacement blowers (for extraction), one liquid/vapor separator, one catalytic oxidizer, and two blowers (for injection). The wells were screened up to 32.5 feet below ground surface.

Confirmatory soil borings showed that the concentrations for all four target contaminants were less than the cleanup standards set in the ROD. The maximum concentration of target contaminants measured in the confirmation soil borings was: chloroform - 0.0099 mg/kg, methylene chloride - not detected, TCE - 0.10 mg/kg, and PCE - 0.28 mg/kg. Approximately 176,500 pounds of total VOCs were extracted during this application, including 3,250 pounds of the four target contaminants. The mass of target compounds removed was almost 5 times greater than the original estimate. According to the RPM, possible reasons for this discrepancy include VOC losses during pre-remediation sampling and analysis, which can cause the results to be biased low; and results not representative of the zone of influence of the SVE wells.

5.0 ENHANCEMENTS/ADDITIONS CASE STUDIES

Case Study Abstract

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

Site Name:
U.S. Department of Energy (DOE), Portsmouth Gaseous Diffusion Plant X-231B

Location:
Piketon, Ohio

Contaminants:
Chlorinated Aliphatics
- 13 VOCs were identified in the soil at PGDP
- Most prevalent VOCs were Trichloroethene (TCE), 1,1,1-Trichloroethane (TCA), 1,1-Dichloroethene (DCE), and methylene chloride
- Concentrations ranged from several hundred to several thousand $\mu g/kg$

Period of Operation:
June 1992

Cleanup Type:
Field demonstration

Technical Information:
Robert L. Siegrist, Prin. Inv., ORNL, (303) 273-3490
Vendors:
Jim Brannigan, Millgard, (313) 261-9760
Steve Day, Geo-Con, (916) 858-0480

Technology:
In Situ Enhanced Soil Mixing (ISESM)
- ISESM consists of soil mixing combined with additional technology
- Four additional technologies were demonstrated at PGDP: vapor extraction with ambient air injection (stripping); vapor extraction with hot air injection (stripping); hydrogen peroxide injection; and grout injection for solidification/stabilization
- 12 soil columns, each 10 ft in diameter and 15 ft deep, were treated in the demonstration
- One additional column was treated by hot air stripping to a depth of 22 ft
- Another additional column was used for a tracer study

Cleanup Authority:
State: Ohio EPA

SIC Code:
9711 (National Security)
Others - information not provided

Points of Contact:
Dave Biancosino, DOE, (301) 903-7961
Jim Wright, DOE, (803) 725-5608

Waste Source:
Waste Treatment Plant/Disposal Pit (waste oil biodegradation units)

Purpose/Significance of Application:
Application of ISESM to remediate fine-grained soils that are difficult to treat with other technologies alone; technology is particularly suited to shallow applications, above the water table.

Type/Quantity of Media Treated:
Soil
- Detailed information provided on soil characteristics, including physical, chemical, and biological properties
- Clay content ranged from 12 to 25%
- 78% of VOCs were present in uppermost 12 ft of soil

Regulatory Requirements/Cleanup Goals:
- Closure plan required 70% mass removal
- No RD&D permit was required

In Situ Enhanced Soil Mixing, U.S. Department of Energy, X-231B, Portsmouth Gaseous Diffusion Plant, Piketon, Ohio (Continued)

Results:
- Soil mixing with each of the 4 additional technologies performed better than the 70% VOC mass removal requirement
- Soil mixing with ambient air stripping achieved >90% removal after 3.75 hrs of treatment
- Soil mixing with hot air stripping achieved >95% removal after 3.75 hrs of treatment
- Soil mixing with peroxidation achieved >70% removal after 1 hr of treatment
- Soil mixing with solidification achieved >90% capture after 1 hr of treatment
- Soil mixing with hot air (thermal) stripping was selected as the remedial option for the site, with cleanup and closure completed in 1994; 628 soil columns at a depth of 22 ft were treated in remediation

Cost Factors:
- Actual capital costs of $1,956,000 were expended for the demonstration, including $481,000 for labor and $500,000 for vendor subcontracts
- Equipment operating costs during demonstration were estimated at $20,000 per day
- Demonstration costs for all four technologies reported as ranging from $150-200/yd^3
- Hot air stripping costs were 5% greater than for ambient air stripping, but achieved cleanup goals faster

Description:
The X-231B waste management unit at the DOE Portsmouth Gaseous Diffusion Plant (PGDP) consists of two waste oil biodegradation areas. The unit was used from 1976 to 1983 for treatment and disposal of waste oils and degreasing solvents, and contributed to contamination of soil and shallow ground water with VOCs. Thirteen VOCs were identified in the soil, including TCE, TCA, DCE, and methylene chloride, at concentrations ranging from several hundred to several thousand μg/kg. The site consists of relatively low permeability soils with elevated clay content.

In situ enhanced soil mixing (ISESM) was demonstrated at the site in 1992. ISESM consists of soil mixing combined with an additional technology. The following four additional technologies were demonstrated at PGDP: vapor extraction with ambient air stripping; vapor extraction with hot air stripping; hydrogen peroxide injection; and grout injection for solidification/stabilization. Three demonstration soil columns were completed for each of the four technologies (12 total). The 12 soil columns were each 10 ft in diameter and 15 ft deep. One additional column was treated by hot air stripping to a depth of 22 ft, and a second additional column was used for a tracer study.

Performance results showed that all four technologies performed better than the 70% VOC mass removal requirement specified by the Ohio EPA. Removals ranged from >70% (for peroxidation) to >95% (for hot air stripping). Based on the results of the demonstration, hot air stripping was selected for site remediation, which was completed in 1994. In situ solidification was more complicated than originally anticipated due in part to difficulty in effectively mixing the dense clay soil in situ and delivering the proper volume of grout. In addition, the solidification process generated secondary liquid wastes from grout delivery trucks and equipment cleanup. An improved "grout-on-demand" system has been developed to minimize waste.

Case Study Abstract

Flameless Thermal Oxidation at the M Area, Savannah River Site, Aiken, South Carolina, in Cooperation With the U.S. Department of Energy Oak Ridge Operations

Site Name:
U.S. Department of Energy (DOE), Savannah River Site,
M Area Process Sewer/Integrated Demonstration Site

Location:
Aiken, South Carolina

Contaminants:
Chlorinated Aliphatics
- Trichloroethene (TCE), tetrachloroethene (PCE), and 1,1,1-trichloroethane (TCA)
- TCE concentrations in the off-gas ranged from 157 to 291 ppm, PCE from 243 to 737 ppm, and TCA from 12 to 21 ppm.

Period of Operation:
April to May 1995

Cleanup Type:
Field demonstration

Vendor:
Bob Wilbourn
Thermatrix, Inc.
(615) 539-9603

Technical Information:
Tim Jarosch, Prin. Inv., WSRC,
(803) 725-5189
Richard Machanoff, HAZWRAP,
(615) 435-3173

SIC Code:
9711 (National Security)
3355 (Aluminum Forming)
3471 (Metal Finishing)

Technology:
Post-Treatment (Air) - Flameless Thermal Oxidation
- Flameless Thermal Oxidizer (FTO) is a commercial technology available from Thermatrix, Inc.
- FTO uses a heated packed bed reactor typically filled with saddle- and spherical-shaped inert ceramic pieces to destroy chlorinated and non-chlorinated volatile organic compounds (VOCs) in vapors extracted by a Soil Vapor Extraction (SVE) system.
- Designed to oxidize off-gases without forming PICs or HAPs; not viewed as an incineration technology.

Cleanup Authority:
State: Air discharge permits for the Savannah River demonstration site are in place with the South Carolina Department of Health and Environmental Control (SCDHEC)

Point of Contact:
Jef Walker, DOE,
(301) 903-7966
Jim Wright, DOE,
(803) 725-5608

Waste Source:
Surface impoundment (unlined settling basin)

Purpose/Significance of Application:
FTO was demonstrated as an alternative technology for treatment of extracted vapors during an SVE application to oxidize off-gases without forming PICs or HAPs.

Type/Quantity of Media Treated:
Off-gases (extracted vapors)
- Information not provided on quantity treated

Regulatory Requirements/Cleanup Goals:
- The Savannah River site maintains air discharge permits for in situ remediation demonstrations associated with VOCs in non-arid soils and ground water.
- No specific regulatory requirements or cleanup goals were identified for the FTO demonstration.

Flameless Thermal Oxidation at the M Area, Savannah River Site, Aiken, South Carolina in Cooperation With the U.S. Department of Energy Oak Ridge Operations (Continued)

Results:
This demonstration was evaluated in terms of destruction and removal efficiency (DRE) for specific VOCs and total chlorinated VOCs (CVOCs).
- The FTO unit achieved >99.995% DRE for PCE and >99.95% for TCE and total CVOCs during a 22-day continuous operation testing stage.
- The FTO unit achieved >99.995% DRE for total CVOCs during a 2.5 day testing period where the influent stream was spiked with 950 to 3060 ppm CVOC.

Cost Factors:
- Capital cost for the FTO unit used in the demonstration was $50,000 (for an electrically heated, 5 scfm unit without an integrated caustic scrubber).
- Total operating costs for FTO technology were estimated at $0.72 per pound of CVOC destroyed, including costs for capital recovery, energy, labor, and maintenance.
- No additional details provided on components of capital or operating costs; however, the authors report that FTO costs less per pound of CVOC destroyed than competing technologies such as thermal catalytic technologies.

Description:
From 1958 to 1985, Savannah River Area M conducted manufacturing operations including aluminum forming and metal finishing. Process wastewater from these operations containing solvents (TCE, PCE, and TCA) was discharged to an unlined settling basin at Savannah River, which lead to contamination of ground water and vadose zone soils. Treatment of vadose zone soils has been the subject of several demonstrations (e.g., in situ air stripping), including this investigation of the technical and economic performance of off-gas treatment technologies.

Flameless thermal oxidation (FTO) is a commercial technology used in a demonstration at Savannah River Area M to treat chlorinated VOCs in off-gasses extracted using a SVE system. FTO uses a heated packed bed reactor typically filled with saddle- and spherical-shaped inert ceramic pieces to destroy chlorinated and non-chlorinated VOCs in vapors extracted by a SVE system. The demonstration was based on pumping from one horizontal SVE well at a flow rate of 5 scfm, and the thermal reaction zone in the FTO was maintained at 1400 to 1700°F. A caustic scrubber was not included in this demonstration because of the relatively small quantity of HCl produced.

This demonstration was evaluated in terms of destruction and removal efficiency (DRE) for specific VOCs and total chlorinated VOCs (CVOCs). The FTO unit achieved >99.99% DRE for PCE, and >99.995% DRE for total CVOCs during a testing period where the influent stream was spiked with CVOC. During the continuous and spike testing phases, no PICs or HAPs were detected in the FTO effluent.

Case Study Abstract

Six Phase Soil Heating at the U.S. Department of Energy, M Area, Savannah River Site, Aiken, South Carolina, and the 300-Area, Hanford Site, Richland, Washington

Site Name:
U.S. Department of Energy (DOE), Savannah River Site (SRS), M Area Process Sewer/Integrated Demonstration Site
(for Hanford Site, see Results)

Contaminants:
Chlorinated Aliphatics
- Trichloroethene (TCE) and tetrachloroethene (PCE)
- TCE concentrations in the sediments ranged from 0 to 181 μg/kg (ppb), and PCE from 0 to 4,529 μg/kg.

Period of Operation:
October 1993 to January 1994

Location:
Aiken, South Carolina

Cleanup Type:
Field demonstration

Technical Information:
Theresa Bergsman, PNL, (509) 376-3638
Phil Gauglitz, (509) 372-1210
Bill Heath, (509) 376-0554
Harry Burkholder (Licensing), PNL, (509) 376-1867

Technology:
Six Phase Soil Heating (SPSH)
- SPSH splits conventional three-phase electricity into six separate electrical phases, with each phase delivered to a single electrode.
- The six electrodes are placed in a hexagonal pattern, with the vapor extraction well located in the center of the hexagon.
- At SRS, the diameter of the hexagon was 30 ft, and 1 to 2 gals/hr of water with 500 ppm NaCl was added at each electrode to maintain moisture. Electrical resistivity tomography (ERT) was used to monitor heating progress.

Cleanup Authority:
State: Air discharge and underground injection control (UIC) permits for the SRS are in place with the South Carolina Department of Health and Environmental Control (SCDHEC).

SIC Code:
9711 (National Security)
3355 (Aluminum Forming)
3471 (Metal Finishing)

Points of Contact:
Kurt Gerdes, DOE EM-50, (301) 903-7289
Dave Biancosino, DOE, (301) 903-7961
Jim Wright, DOE, (803) 725-5608

Waste Source:
Surface impoundment (unlined settling basin)

Purpose/Significance of Application:
SPSH was demonstrated as an alternative technology for enhancing removal of contaminants from clayey soils during an SVE application

Type/Quantity of Media Treated:
Soil and Sediment
The contaminated target zone was a ten-foot thick clay layer at a depth of approximately 40 feet, underlain by a thick section of relatively permeable sands with thin lenses of clayey sediments.

Regulatory Requirements/Cleanup Goals:
- The demonstration was covered by permits issued by the SCDHEC, including an air quality permit and a UIC permit (because of the addition of NaCl-bearing water to the electrodes).
- No specific regulatory requirements or cleanup goals were identified for the SPSH demonstration.

Six Phase Soil Heating at the U.S. Department of Energy, M Area, Savannah River Site, Aiken, South Carolina, and the 300-Area, Hanford Site, Richland, Washington (Continued)

Results:
- Temperature in the clay zone increased to 100°C within 8 days and held at 100-110°C for 25-day demonstration.
- 19,000 gallons of water were removed from the soil as steam; approximately 5,000 gallons of water were added to maintain electrode conductivity.
- Median removal of PCE from the soil was 99.7%
- 180 kg of PCE and 23 kg of TCE were removed from the soil within the heated zone.
- SPSH at the Hanford site was conducted in 1993 on an uncontaminated area.
- Results from Hanford were used to improve process understanding, refine system design (e.g., of electrodes), and address scale-up issues.

Cost Factors:
- No data are provided on the capital or operating costs for the two demonstrations.
- An analysis of the capital and operating costs comparing SPSH and SVE technologies was made based on the following assumptions: a plume 100 ft in diameter; depth from 20 to 120 ft; energy demand 200 kW-hr per yd^3; target contaminants are VOCs and semi-VOCs.
- SPSH was shown to have a lower cost than SVE ($86/$yd^3$ compared with $576/$yd^3$) and to require less time for remediation (5 yrs compared with 50 yrs).

Description:
From 1958 to 1985, Savannah River Area M conducted manufacturing operations including aluminum forming and metal finishing. Process wastewater from these operations containing solvents (TCE, PCE, and TCA) was discharged to an unlined settling basin at Savannah River, which lead to contamination of ground water and vadose zone soils. Treatment of vadose zone soils has been the subject of several demonstrations (e.g., in situ air stripping), including this investigation of the technical and economic feasibility of six phase soil heating (SPSH) technology.

At SRS, SPSH was used to increase the removal efficiency of SVE for a clayey soil contaminated with TCE and PCE. At Hanford, SPSH was demonstrated on an uncontaminated site to improve process understanding, refine system design (e.g., of electrodes), and address scale-up issues. SPSH splits conventional three-phase electricity into six separate electrical phases, with each phase delivered to a single electrode. The six electrodes are placed in a hexagonal pattern, with the vapor extraction well located in the center of the hexagon.

Results from the SRS demonstration showed that SPSH increased the temperature in the clay zone to 100°C within 8 days and maintained it at 100-110°C for a 25 day demonstration. In addition, there were 19,000 gallons of water removed from the soil as steam, and approximately 5,000 gals of water added to maintain electrode conductivity. The median removal of PCE from the soil was 99.7%, with overall results showing that 180 kg of PCE and 23 kg of TCE were removed from the soil within the heated zone. Operating difficulties included drying out of the electrodes and shorting of the thermocouples. The system design was improved to overcome these difficulties.

6.0 OTHER IN SITU TECHNOLOGIES

Case Study Abstract

Hydraulic and Pneumatic Fracturing, U.S. Department of Energy (Portsmouth Gaseous Diffusion Plant, Ohio), Department of Defense, and Commercial Sites

Site Name:
1. U.S. Department of Energy (DOE), Portsmouth Gaseous Diffusion Plant (PGDP)
2. DoD (e.g., Tinker AFB) and Commercial sites (various)

Contaminants:
- Demonstrations conducted at sites contaminated with Volatile Organic Contaminants (VOCs) (including Trichloroethene (TCE)), Dense Nonaqueous Phase Liquids (DNAPLs), and at uncontaminated sites

Period of Operation:
July 1991 - August 1996 (multiple demos during this time period)

Location:
Piketon, Ohio (for PGDP)

Cleanup Type:
Field demonstration

Technical Information:
Pneumatic: J. Liskowitz/T. Keffer, ARS, (908) 739-6444
John Schuring, NJIT, (201) 596-5849
Hydraulic: L. Murdoch, Univ. of Cinc., (513) 556-2519
W. Slack, FRX, (513) 556-2526
R. Siegrist, ORNL, Col. Sch. of Mines, (303) 273-3490

Technology:
Hydraulic and Pneumatic Fracturing
- Hydraulic fracturing equipment includes lance, notch tool, slurry mixer, and pump
- Gel-laden proppant is pumped into notch under 60 psig to create a fracture
- Pneumatic fracturing equipment includes high-pressure air source, pressure regulator, and receiver tank with inline flow meter and pressure gauge
- Air is injected at 72.5-290 psi for <30 seconds using a proprietary nozzle
- Design considerations include formation permeability, type, and structure; sand proppant; state of stress; site conditions; and depth
- Fracturing used in conjunction with other in situ technologies such as SVE, bioremediation, and pump and treat

Cleanup Authority:
Information not provided

SIC Code:
9711 (National Security)
Others - information not provided

Points of Contact:
Skip Chamberlain, DOE, (301) 903-7248
James Wright, DOE, (803) 725-5608

Waste Source:
Tinker - Underground Storage Tank
Others - Information not provided

Type/Quantity of Media Treated:
Soil and Ground Water
- Generally applicable in low permeability formations
- At PGDP, was used at uncontaminated site underlain by low permeability clays and silts to a depth of approximately 15-22 ft

Purpose/Significance of Application:
Demonstrations of technology used to increase hydraulic conductivity, contaminant mass recovery, and radius of influence (for example, in a SVE application)

Regulatory Requirements/Cleanup Goals:
- No special permits were required for use in the demonstrations
- Some states may be concerned about injection of fluids and other materials that may alter the pH of the subsurface

Hydraulic and Pneumatic Fracturing, U.S. Department of Energy (Portsmouth Gaseous Diffusion Plant, Ohio), Department of Defense, and Commercial Sites (Continued)

Results:
- Hydraulic fracturing demonstrations showed mass recovery increased from 2.8-50 times, and radius of influence from 25-30 times
- Pneumatic fracturing at Tinker Air Force Base increased product thickness in recovery well from 1.5 to 20.2 ft
- Pneumatic fracturing at PGDP doubled hydraulic conductivity, and increased radius of influence by 33% after one day of pumping

Cost Factors:
- Capital and annual costs not provided for demonstrations
- Hydraulic fracturing projected to cost $5,400 for one-time costs, and $5,700 for daily costs (corresponding to $950-1,425 per fracture, for 4-6 fractures)
- Pneumatic fracturing projected to be similar to those for hydraulic fracturing ($400-1,425 per fracture)
- Pneumatic fracturing at a SITE demonstration estimated at $140/lb of TCE removed; other estimates predict pneumatic fracturing cost of $8-17/yd^3 soil treated

Description:
Hydraulic and pneumatic fracturing are technologies that can enhance access to the subsurface for remediation of contaminants above and below the water table. Enhanced access is provided by creating new or enlarging existing fractures in the subsurface. These fractures enhance the performance of in situ remediation technologies such as SVE, bioremediation, and pump and treat by increasing the soil permeability; increasing the effective radius of recovery or injection wells; increasing potential contact area with contaminated soils; and intersecting natural features. Fracturing can also be used to improve delivery of materials to the subsurface (e.g., nutrients).

A number of demonstrations of hydraulic and pneumatic fracturing have been conducted to show technology applicability and performance in a variety of settings. Hydraulic fracturing demonstrations have showed mass recovery increases from 2.8-50 times, and radius of influence increases from 25-30 times. Pneumatic fracturing demonstrations have been conducted at Tinker Air Force Base and PGDP, with results provided in terms of increased product thickness in recovery wells and increases in hydraulic conductivity and radius of influence. Hydraulic fracturing is commercially available from several companies, while pneumatic fracturing has been patented by the New Jersey Institute of Technology (NJIT). The NJIT has licensed pneumatic fracturing to Accutech Remedial Services (ARS). While hydraulic fracturing produces larger apertures and can be performed at greater depths than pneumatic fracturing, the addition of water in hydraulic fracturing may create a larger volume of contaminated media possibly requiring remediation. Prior to proposing fracturing, sites should be analyzed for permeability. Sites with extensively fractured strata will have permeabilities that are high enough that fracturing may not be required.

Case Study Abstract

Frozen Soil Barrier Technology at the SEG Facilities, Oak Ridge, Tennessee in Cooperation with U.S. Department of Energy Oak Ridge Operations

Site Name: Scientific Ecology Group (SEG), Gallaher Road Facility	**Contaminants:** None - Surrogate solution (200 ppm Rhodamine-WT) were used to test the integrity characteristics of the barrier.	**Period of Operation:** May 12 - October 10, 1994
Location: Oak Ridge, Tennessee		**Cleanup Type:** Field demonstration
Technical Information: Rick Swatzell, Prin. Inv., Martin Marietta Energy Systems, Inc. (615) 435-3126 Ray Peters, SEG (615) 376-8194	**Technology:** Frozen Soil Barrier - Uses refrigeration to freeze soils and provide barrier/containment for hazardous and/or radioactive contaminants in soil and ground water. - Demonstration facility was "V"-shaped, with dimensions of 56 by 56 feet outside and 33 by 33 feet inside; maximum depth was 28 feet; - Refrigerant pipes were installed around circumference of facility in a double-rowed configuration with an ice wall allowed to grow together between the pipes and forming a barrier.	**Cleanup Authority:** None - demonstration conducted at a nonhazardous site
SIC Code: Not Applicable (not a contaminated site)		**Management Information:** Jef Walker, DOE EM-50 Plumes Focus Area Program Manager, (303) 903-7966
Waste Source: Not Applicable (not a contaminated site)	**Type/Quantity of Media Treated:** Soil - Subsurface soils consisted of 13 to 22 feet of fill soils overlying residual soils. Fill soils consisted of stiff to hard red-brown silty clay, with varying amounts of chert fragments. Residual soils consisted of stiff to soft red-brown to brown silty clay and clayey silt, with varying amounts of chert fragments. - Soil density measured as 108.8 lb/ft^3. - Average soil moisture content ranged from 26.5 to 33.9%. - 8,175 cubic feet of soil contained by the frozen barrier. - 35,694 cubic feet of soil composed frozen barrier.	
Purpose/Significance of Application: Frozen soil barrier technology has been demonstrated for controlling waste migration in soils.		

Regulatory Requirements/Cleanup Goals:
No regulatory requirements or cleanup goals were identified for this demonstration because it was conducted at a nonhazardous site.

Results:
This demonstration was evaluated using the following four types of performance testing: 1) computer model validation; 2) soil movement testing, including heat grid tests; 3) barrier diffusion and leaking tank tests; and 4) barrier integrity testing. The barrier diffusion and leaking tank tests were used to demonstrate containment by the frozen barrier wall by releasing Rhodamine-WT from a tank inside the containment structure and measuring its potential diffusion across the barrier wall.

- Tests showed that Rhodamine was found only inside the barrier region, confirming barrier integrity.
- Tests showed that Rhodamine migrated approximately two feet in unfrozen soils, while essentially no Rhodamine was found below open-ended well casings within the freeze barrier.

Frozen Soil Barrier Technology at the SEG Facilities, Oak Ridge, Tennessee in Cooperation with U.S. Department of Energy Oak Ridge Operations (Continued)

Cost Factors:
- Total capital costs for the SEG demonstration were $481,427.
- Maintenance costs for the demonstration were estimated as $40,000 per year ($3322 per month).
- No additional details provided on components of capital or maintenance costs.
- Unit costs identified for this technology ranged from $4 to $14 per cubic foot of iced formed, and are compared with unit costs for grout systems ranging from $1 to $37 per cubic foot.
- Report authors indicated that a more realistic cost (i.e., for an actual remedial activity) for this type of technology would be $332,754, assuming that extra sensors and test support were not needed, if equipment were leased instead of purchased, and barrier thickness was decreased (which would mean less drilling, energy consumption, etc.).

Description:
Frozen soil barrier technology was demonstrated under the sponsorship of the U.S. DOE In Situ Remediation Integrated Demonstration Program at a nonhazardous site on SEG property at the Gallaher Road Facility in Oak Ridge Tennessee. Frozen soil barrier technology has been used for a number of years in large-scale civil engineering projects to seal tunnels, mine shafts, and other subsurface structures against flooding, and to stabilize soils during excavation. Advantages of frozen soil barrier technology include: 1) it can provide complete containment; 2) it uses benign material (water/ice) as a containment medium; 3) frozen barriers can be removed by thawing; and 4) frozen barriers can be repaired in situ (by injecting water into the leaking area).

At the SEG demonstration, a "V"-shaped containment structure was constructed 56 feet long by 56 feet wide by 28 feet deep. Refrigerant piping was used to create an area of frozen soil ranging from 5 to 15 feet thick. Several types of performance testing were performed, including barrier diffusion and leaking tank tests, based on use of a surrogate solution containing 200 ppm of Rhodamine-WT. The barrier diffusion and leaking tank tests showed that Rhodamine was found only inside the barrier region, confirming barrier integrity, and that Rhodamine migrated approximately two feet in unfrozen soils, while essentially no Rhodamine was found below open-ended well casings within the freeze barrier.

Determining the suitability of this technology for applications for arid/sandy environments will require development of methods for homogeneously adding and retaining moisture in the soils. In addition, technology applications in fine-grained soils around structures may be limited because of soil movement.

Case Study Abstract

ResonantSonic Drilling

Site Name: U.S. Department of Energy (DOE), 1. Hanford Site 2. Sandia National Laboratory	**Contaminants:** Not used at contaminated sites	**Period of Operation:** 1992-1994 (see results)
Location: 1. Richland, Washington 2. Albuquerque, New Mexico		**Cleanup Type:** Field demonstration
Technical Information/Vendor: Information not provided	**Technology:** ResonantSonic Drilling - Used to access the subsurface for installation of monitoring and/or remediation wells and for collection of subsurface materials - Uses a combination of mechanically generated vibrations and limited rotary power to penetrate soil - Drill head consists of two counter rotating, out-of-balance rollers that cause the drill pipe to vibrate - Transmits 50,000 to 280,000 lbs of force to the drill pipe; drills hole diameters up to 16 inches - Newer designs also include drill head rotation capability	**Cleanup Authority:** Not used at contaminated sites
SIC Code: 9711 (National Security) Others - information not provided		**Points of Contact:** Information not provided
Waste Source: Not used at contaminated sites	**Type/Quantity of Media Treated:** Soil and Sediment - At Hanford, most drilling occurred in two facies: a coarse-grained sand and granule-to-boulder gravel; and a fine-to-coarse-grained sand and silt - At Sandia, sediments are extremely heterogeneous, complexly-interlayered units consisting of sands, gravels, and cobbly units, with discontinuous low-permeability layers present	
Purpose/Significance of Application: ResonantSonic drilling, an alternative to traditional drilling technologies, was shown in some applications to be less costly and produce less drilling wastes than cable tool or mud rotary technologies.		
Regulatory Requirements/Cleanup Goals: - Not used at contaminated sites - Does not require addition of fluids to a well, which in some states is restricted		

ResonantSonic Drilling (Continued)

Results:
- Initial Hanford demonstration averaged 23.9 ft drilled per day (8.9 ft/day, including downtime)
- Well depths ranged from 30 to 227 ft
- Provided intact lithologic samples
- Second Hanford demonstration included boreholes drilled at 45° angles, with wells up to 172 ft long
- Sandia demonstration included 3 different drill rigs, with 5-10% less down time than at Hanford

Cost Factors:
- Capital and operating costs for the demonstrations are not provided in the report
- A comparison of cost ($/ft) for ResonantSonic, cable-tool, and mud-rotary drilling is provided based on a hypothetical scenario, for regular and difficult drilling
- ResonantSonic drilling ranged from $208-270/ft, cable-tool from $600-758/ft, and mud-rotary from $221-951/ft, depending on type of site and type of drilling

Description:
ResonantSonic drilling has been demonstrated at the U.S. DOE Hanford and Sandia sites as an alternative to cable tool and rotary-mud drilling. This technology is used for installation of monitoring and/or remediation wells, and for collection of subsurface materials for environmental restoration applications. Advantages of ResonantSonic drilling include: lower cost per foot for drilling, can provide relatively undisturbed continuous core samples; uses no drilling fluids and minimizes waste generation; and can be used to drill slant (angle) holes.

ResonantSonic drilling uses a combination of mechanically generated vibrations and limited rotary power to penetrate soil. The drill head consists of two counter-rotating, out-of-balance rollers that cause the drill pipe to vibrate, and transmit force to the drill pipe. From 1991 to 1994, this technology was used on uncontaminated soil in two demonstrations at Hanford and three at Sandia, with an additional demonstration planned at Hanford. These demonstrations included drilling hole diameters up to 16 inches.

Results from these demonstrations were used to improve system design and operation. For example, the initial Hanford demonstration had high percentages of downtime, while later demonstrations at Sandia resulted in much less downtime. These demonstrations included wells drilled up to 227 ft deep, and several wells drilled at 15-45° angles. Further, this technology shows significant waste minimization compared to mud rotary. However, heating core materials remains an issue where no fluid is used to cool the formation and under difficult drilling conditions. ResonantSonic generated core temperatures from 70°F to 140°F under difficult drilling conditions at Hanford. In addition, few drilling companies currently provide ResonantSonic drilling services. This should be considered in selecting this drilling alternative.