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Remediation Case Studies: Bioremediation and Vitrification

VOLUME 5

Federal Remediation Technologies Roundtable

Prepared by the

Member Agencies of the Federal Remediation Technologies Roundtable

Remediation Case Studies: Bioremediation and Vitrification

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Federal Remediation Technologies Roundtable

Environmental Protection Agency
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- U.S. Air Force
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Department of Energy
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July 1997

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FOREWORD

This report is a collection of six case studies of bioremediation and two case studies of vitrification 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

Ordering Information

These documents are available free of charge by fax or mail from NCEPI (allow 4-6 weeks for delivery), at the following address:

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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).

TABLE OF CONTENTS

	Page
FOREWORD	iii
ORDERING INSTRUCTIONS	iv
INTRODUCTION	1
BIOREMEDIATION CASE STUDIES	7
Land Treatment at the Burlington Northern Superfund Site, Brainerd/Baxter, Minnesota	9
Composting at the Dubose Oil Products Co. Superfund Site, Cantonment, Florida	41
Slurry Phase Bioremediation at the Southeastern Wood Preserving Superfund Site, Canton, Mississippi	75
Cost Report: Windrow Composting to Treat Explosives-Contaminated Soils at Umatilla Army Depot Activity (UMDA)	107
In Situ Bioremediation Using Horizontal Wells, U.S. Department of Energy, M Area, Savannah River Site, Aiken, South Carolina	155
Lasagna™ Soil Remediation at the U.S. Department of Energy Cylinder Drop Test Area, Paducah Gaseous Diffusion Plant, Paducah, Kentucky	185
VITRIFICATION CASE STUDIES	203
In Situ Vitrification at the Parsons Chemical/ETM Enterprises Superfund Site, Grand Ledge, Michigan	205

TABLE OF CONTENTS (Continued)

Page

In Situ Vitrification at the U.S. Department of Energy Hanford Site, Richland, Washington; Oak Ridge National Laboratory WAG 7, Oak Ridge, Tennessee; and Various Commercial Sites 225

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.

This volume contains reports on eight projects. Four of the projects were full-scale, ex situ projects using bioremediation - two composting, one slurry phase, and one land treatment. Two of the projects were large scale demonstrations of in situ bioremediation - one using gaseous nutrient injection and the other a patented process combining bioremediation and vapor extraction. One of the two vitrification projects is a final report on the first full-scale remediation of a Superfund site using vitrification (preliminary results from this project were described in an interim report in 1995; however, since that time, the melt cooled sufficiently for sampling, and final results are now available). The other report on vitrification provides a status update on several vitrification projects.

Table 1 provides a summary including information on technology used, contaminants and media treated, and project duration for the eight bioremediation and vitrification projects in this volume. This table also notes highlights of the technology applications. Table 2 summarizes cost data, including information on quantity of media treated and contaminant removed. In addition, Table 2 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 2 as reported in the case studies, and have not been adjusted for inflation to a common year basis. The dollar values shown in Table 2 should be assumed to be dollars for the time period that the project was in progress (shown on Table 1 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 2 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.

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.

[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.

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. 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 2. 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*
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
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Calculated Cost for Treatment**
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***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.

BIOREMEDIATION CASE STUDIES

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

Case Study Abstract

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

Site Name:
Burlington Northern Superfund Site

Location:
Brainerd/Baxter, Minnesota

Vendor:
Mindy L. Salisbury
Remediation Technologies, Inc. (ReTeC)
413 Waconta St., Suite 400
St. Paul, MN 55110
(612) 222-0841

SIC Code:
2491 B (Wood Preserving using Creosote)

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

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")

Period of Operation:
May 1986 - October 1994

Cleanup Type:
Full-scale cleanup

Cleanup Authority:
CERCLA
- Enforcement Decision Document Date June 4, 1986
- PRP Lead

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

Purpose/Significance of Application:
Full-scale application of land treatment at a creosote-contaminated site

Type/Quantity of Media Treated:
Soil and Sludge
- 13,000 cubic yards of soil and sludge

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.

COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for a land treatment application at the Burlington Northern Superfund site, in Brainerd/Baxter, Minnesota. Land treatment was used at the Burlington Northern site to treat soil and sludge contaminated with polynuclear aromatic hydrocarbons (PAHs) and other non-halogenated semivolatile organic compounds, including naphthalene, acenaphthylene, acenapthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b and k)fluoranthenes, benzo(a)pyrene, benzo(ghi)perylene, dibenzo(a,h)anthracene, indeno(1,2,3)pyrene, and phenols.

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 1980's, 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 (acenaphthene, a two-ring PAH), 7,902 mg/kg (phenanthrene, a three-ring PAH), and 10,053 mg/kg (fluoranthene, a four-ring PAH). Concentrations of benzene-extractable constituents in the surface impoundment soils ranged from 66,100 to 112,500 mg/kg.

In April, 1985, a three-party consent agreement for this site was signed by Burlington Northern, the Minnesota Pollution Control Agency (MPCA), and EPA. Based on the 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. In addition, a RCRA Part B permit was issued for this site which specified that the concentration of methylene chloride extractable (MCE) hydrocarbons (a replacement for benzene extractables) and total PAHs (the sum of 17 specific PAHs) in the treatment zone would not be greater than 21,000 mg/kg and 8,632 mg/kg, respectively. While the permit also specified that the treatment zone would be detoxified to "within Microtox® limits," no quantitative limits were provided in the permit.

The land treatment unit (LTU) used in this application was constructed at Burlington Northern in 1985, with 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). The LTU was constructed in layers, over a base of 100 mm thick HDPE, silty sand ballast, gravel, and clean, silty sand. Two-foot wide leachate collection drains were installed in the gravel layer, on 100-foot centers. 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. In July and August, 1995, after completion of LTU operation, Burlington Northern placed a cover over the LTU.

EXECUTIVE SUMMARY (CONT.)

Soil sampling and analysis were performed at the beginning and end of each of the nine treatment seasons, and again throughout the depth of the LTU at the completion of treatment. The yearly analytical data indicate that the average concentrations for MCE hydrocarbons was reduced from 64,000 to 33,000 mg/kg, and for total PAHs from 9,733 to 1,854 mg/kg, over the nine treatment seasons. The analytical data from the LTU at the completion of treatment indicate that MCE hydrocarbons ranged from 24,800 to 26,900 mg/kg, and total PAHs from 608 to 795 mg/kg, throughout the depth of the treated soil and sludge. In addition, at the completion of treatment, Microtox® EC 50 testing (5 minute, 15°C) showed residual toxicity ranging from 4.9 to 15.3. As shown by these data, the LTU met the cleanup goal for total PAHs, but did not meet the cleanup goal for MCE hydrocarbons. According to the Remedial Action Report, the soil was not treated to "within Microtox® limits"; however, as stated previously, these limits were not provided in the available information. In addition, the total PAH cleanup requirement was met for all nine treatment seasons. Because the LTU did not meet the cleanup requirements for MCE hydrocarbons or toxicity, Burlington Northern was required to implement a contingency procedure in their permit and place a cover over the LTU.

The land treatment application at Burlington Northern was PRP-lead, and no information on actual costs incurred (before-treatment, treatment, or after-treatment, as appropriate) is provided in the available references. In addition, no information is provided on unit costs (e.g., costs per cubic yard of soil and sludge treated) for this application.

SITE INFORMATION

Identifying Information:

Burlington Northern Superfund site
Brainerd/Baxter, Minnesota
CERCLIS # MND000686196
Enforcement Decision Document Date: June 4, 1986

Treatment Application:

Type of Action: Remedial
Treatability Study Associated with Application? Yes
(refer to Reference 15 for additional information)
EPA SITE Program Test Associated with Application? Yes
A SITE program test of slurry phase biological treatment was conducted on a pilot-scale basis in 1991 using contaminated soil from Burlington Northern. Reference 20 contains additional information on the SITE program test.
Period of Operation: May 1986 - October 1994
Quantity of Material Treated During Application: 13,000 cubic yards of soil and sludge
This quantity consists of 8,500 cubic yards of soil and sludge excavated from two surface impoundments, 3,500 cubic yards of soil excavated from other areas of interest at the site (process area, drip track area, and black dock area), and 1,000 cubic yards of sand, gravel, and other soil from stockpile closure activities. [1]

Background

Historical Activity that Contributed to Contamination at the Site: Creosote wood preserving

Corresponding SIC Code: 2491B (Wood Preserving Using Creosote)

Waste Management Practice that Contributed to Contamination: Manufacturing Process, Surface Impoundments

Site History: The Burlington Northern Superfund site (Burlington Northern) is located partly in Baxter and partly in Brainerd, Minnesota, as shown in Figure 1. Burlington Northern Railroad operated a railroad tie treating plant at the site between 1907 and 1985. The wood preserving process used at the site involved pressure treatment using a heated creosote/coal tar or creosote/fuel oil mixture. Wastewater generated from the wood preserving process was discharged to two shallow, unlined surface impoundments for disposal. The first impoundment (referred to as the CERCLA impoundment) was approximately 60,000 square feet in area. This impoundment filled with sludge and was buried under clean fill in the 1930s. A second impoundment (referred to as the RCRA impoundment) was used from the 1930s until October

SITE INFORMATION (CONT.)

Background (cont.)

1982. EPA determined that the use of these surface impoundments had resulted in contamination of both the soil and groundwater beneath the ponds. Disposal pond soil was classified as RCRA hazardous waste K001, under 40 CFR 261.32. [3, 23]

The soil at three additional areas at Burlington Northern also was determined to be contaminated (the process area, drip track area, and black dock area). These areas are shown on Figure 2. Tie treating operations were completed in the retort building in the process area. Creosote used in the treatment process was also stored in aboveground tanks in this area. Following pressure treatment, the ties were moved to the drip track area for drying. Treated ties were then transported to the black dock area for storage prior to transport off site. [1]

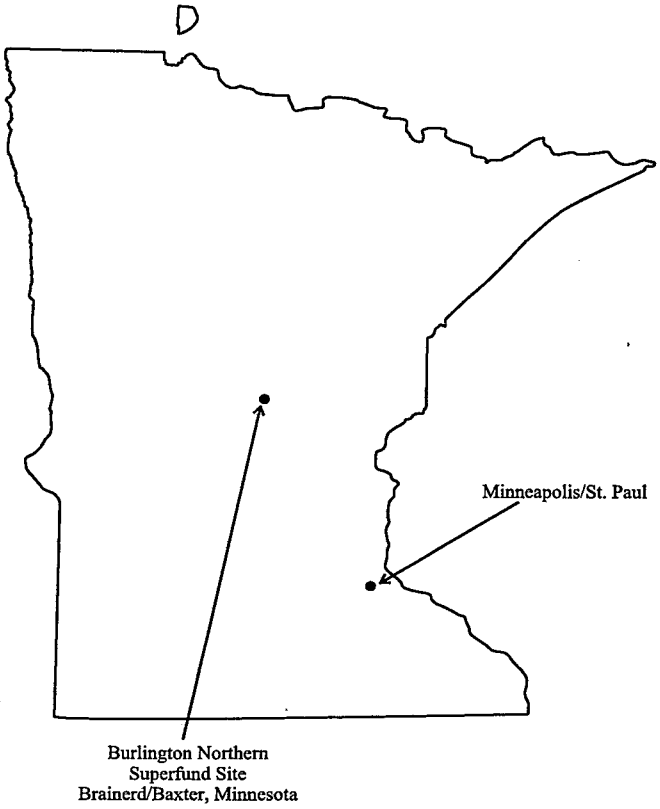

Figure 1. Site Location

Regulatory Context: In April 1985, a three-party consent agreement was signed by Burlington Northern, the Minnesota Pollution Control Agency (MPCA), and EPA. The consent agreement detailed specific actions and studies to be undertaken concerning the two surface impoundments and three additional areas of contaminated soil. Activities included site monitoring, preparing a treatment study, preparing a feasibility study, submitting closure and post-closure plans, and implementing corrective actions. Based on the consent agreement, EPA issued an Enforcement Decision Document (a predecessor to a Record of Decision - ROD) in June 1986, which identified actions to control the source of contamination, including treatment of soils and sludges, and to prevent hazardous substances from migrating away from the contaminated site. The Enforcement Decision Document required Burlington Northern to excavate and treat soils and sludges which were visibly contaminated and which contained free oils that could migrate to groundwater. [3]

SITE INFORMATION (CONT.)

Background (cont.)

Remedy Selection: The following three alternatives for treatment of contaminated soils and sludges were considered for the site:

- On-site land treatment of contaminated soils and sludges;
- On-site incineration of contaminated soils and sludges; and
- On-site land treatment of contaminated soils, and off-site incineration of sludges.

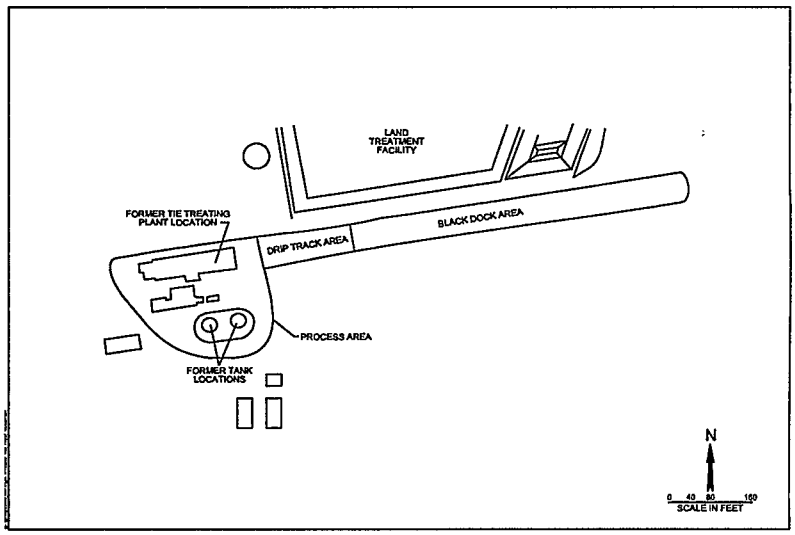

Figure 2. Additional Areas of Contaminated Soil at Burlington Northern [1]

On-site land treatment of contaminated soils and sludges was selected for this site because it was identified as protective of human health and the environment, and was the lowest cost alternative. [3]

In 1984, bench- and pilot-scale tests were conducted to evaluate the feasibility of using land treatment for the contaminated soils and sludges from the lagoons. The study consisted of six pilot-scale test plots and six bench-scale reactors which varied in the initial creosote concentration. These tests showed that land treatment was feasible for remediation of these materials. [15]

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Management: PRP lead
Oversight: EPA/State

Remedial Project Manager:

Tony Rutter
U.S. EPA Region V
77 W. Jackson Boulevard
Mail Code HSR-6J
Chicago, Illinois 60604
(312) 886-8961

State Contact:

Fred M. Jenness
Minnesota Pollution Control Agency
Hazardous Waste Division
Regulatory Compliance Section
Permit and Review Unit
530 Lafayette Road North
St. Paul, Minnesota 55155-4194
(612) 297-8470

Treatment Vendor:

Mindy L. Salisbury
Remediation Technologies, Inc. (ReTeC)
413 Waconta St., Suite 400
St. Paul, MN 55110
(612) 222-0841

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: soil and sludge

Contaminant Characterization

Primary Contaminant Groups: Polynuclear Aromatic Hydrocarbons (PAHs), Other Semivolatiles - Nonhalogenated

The Enforcement Decision Document identified visibly contaminated soils as being heavily stained, dark brown to black in color, visibly oily, and usually having a pronounced creosote odor. Table 1 shows the average concentration for PAHs, benzene extractables, and total phenols in visibly contaminated soils in the CERCLA (pre-1930s) and RCRA (post-1930s) surface impoundments. In addition, concentrations ranging from 5 to 30 percent for benzene extractables and 3 to 15 percent for total PAHs were reported for the visibly contaminated soils. [3]

No analytical data were contained in the available references on the concentrations of specific constituents in visibly-contaminated soils in the three additional areas of contaminated soil.

Table 1. Average Concentrations for Visibly-Contaminated Soils in Surface Impoundments [3]

Constituent	CERCLA Surface Impoundment (mg/kg)	RCRA Surface Impoundment (mg/kg)
Naphthalene	3,105	6,494
Acenaphthylene	2,280	3,651
Acenaphthene	10,180	21,319
Total 2-Ring PAHs	15,565	31,464
Fluorene	1,505	2,497
Phenanthrene	3,305	7,902
Anthracene	1,085	1,440
Total 3-Ring PAHs	5,895	11,839
Fluoranthene	4,650	10,053
Pyrene	5,015	9,481
Benzo(a)anthracene	722	1,670
Chrysene	889	2,392
Benzo(b)fluoranthene	373	1,756
Benzo(k)fluoranthene	244	461
Benzo(a)pyrene	303	536
Benzo(ghi)perylene	137	671
Dibenz(a,h)anthracene	78	192
Indeno(1,2,3)pyrene	111	120

MATRIX DESCRIPTION (CONT.)

Contaminant Characterization (cont.)

Table 1 (Continued)

Constituent	CERCLA Surface Impoundment (mg/kg)	RCRA Surface Impoundment (mg/kg)
Total 4- and 5-Ring PAHs	12,522	27,330
Total PAHs	33,982	70,633
Benzene Extractables	66,100	112,500
Total Phenols	16	65

Matrix Characteristics Affecting Treatment Cost or Performance

The major matrix characteristics affecting cost or performance for this technology and the values measured for each are shown in Table 2.

Table 2. Matrix Characteristics

Parameter	Value	Measurement Method
Soil Classification	Information not provided	Information not provided
Clay Content and/or Particle Size Distribution	Information not provided	Information not provided
pH	Information not provided	N/A
Field Capacity	Information not provided	Information not provided

N/A - Measurement method not reported for this parameter because resulting value not expected to vary among measurement procedures.

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology Type: Land Treatment

Supplemental Treatment Technology Type: None

Soil Vapor Extraction System Description and Operation

In 1985, a land treatment unit (LTU) was constructed at the Burlington Northern site. The LTU had outer dimensions of approximately 300 by 495 feet (about 150,000 ft^2) and an area available for treatment of approximately 255 by 450 feet (about 115,000 ft^2). The LTU was constructed over the former RCRA surface impoundment (after the visibly contaminated soils and sludges had been removed). A diagram of the LTU, the leachate collection sump, and the temporary waste stockpile is shown in Figure 3. [1]

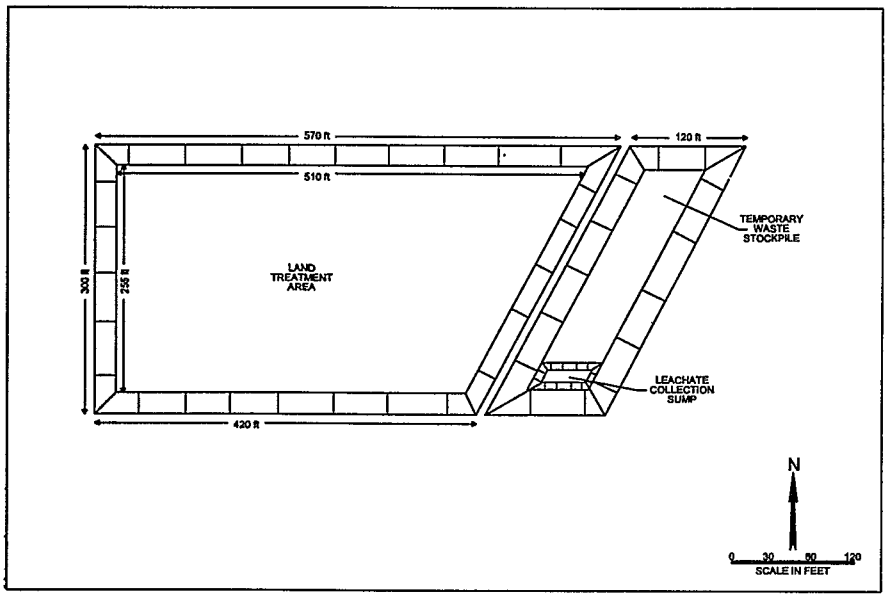

Figure 3. Land Treatment Unit Constructed at Burlington Northern [1]

LTU Construction

The LTU was constructed with the following layers, as shown in Figure 4:

- A 100-millimeter thick high density polyethylene (HDPE) membrane;
- An 18-inch layer of silty sand ballast;
- A 6-inch layer of gravel; and
- A 24-inch layer of clean, silty sand.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Soil Vapor Extraction System Description and Operation (Cont.)

Depth (Inches Below Surface)	
0	LTU Surface
8	Material Treated in 1994
14	Material Treated in 1993
20	Material Treated in 1992
26	Material Treated in 1991
32	Material Treated in 1990
38	Material Treated in 1989
44	Material Treated in 1988
50	Material Treated in 1987
56	Material Treated in 1986
80	Clean, Silty Sand
86	Gravel
102	Silty Sand Ballast
	100-mm HDPE liner

Figure 4. LTU Construction Layers [1]

The HDPE membrane covered the bottom and the side slopes of the LTU. The bottom of the LTU sloped downward 0.5 percent to the south and west. The LTU was surrounded by containment berms (3 to 1 side slopes) to prevent surface run-on from entering the treatment unit. [1]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Soil Vapor Extraction System Description and Operation (Cont.)

The gravel layer operated as a leachate collection system and as a "marking layer" during treatment. Two-foot wide leachate collection drains on 100-foot centers were located in the gravel layer, extending through the gravel layer into the sand ballast to within 1 foot of the liner. The drains were filled with gravel, and perforated pipe wrapped with filter fabric were installed in the drains to collect leachate. The collection system carried leachate to a sump, which was filled with 6-inch rounded cobbles and had a capacity of 50,000 gallons. [1, 2]

LTU Operation

Contaminated soil and sludge excavated from the surface impoundments and other areas of interest at the site were stored in a temporary stockpile located adjacent to the LTU. Starting in May 1986, between 1,100 and 1,500 cubic yards of soil and sludge were spread over the LTU to a depth of 6-8 inches each year. Dump trucks were used to transport the contaminated materials from the temporary stockpile to the treatment area. [1]

Land treatment was conducted from May through October each year (referred to as the treatment season), and the system was operated for 9 treatment seasons, between 1986 and 1994. Weather permitting, the treatment area was cultivated weekly to a 12-inch depth with a tractor-mounted rototiller. Thus, some mixing occurred between the current lift and the previous year's lift. One reason for this mixing was to increase the microbial population in the current year's lift. An agricultural disk was used on a periodic basis to level the surface of the LTU. About once every three years, a 24-inch ripper was used to break up the compacted soil layer beneath the 12-inch tilling zone. Irrigation of the LTU was performed periodically to maintain a soil moisture content of approximately 10 percent by weight. Soil pH was maintained between 6.2 and 7.0 with lime addition, and the carbon:nitrogen:phosphorus ratio was maintained near 100:2:1, with cow manure application. [1, 2]

Leachate from the LTU, collected in the sump, was discharged to an on-site equalization tank. Some of the leachate was applied to the LTU as irrigation water, while the remainder was discharged to a local sewer system. [1]

After completion of LTU operation, Burlington Northern placed a cover over the LTU during July and August 1995. EPA reviewed the design documents and approved the design prior to construction. The closure was approved by EPA on January 8, 1996. [22]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameters affecting cost or performance for this technology and the values measured for each are shown in Table 3.

Table 3. Operating Parameters [1, 5]

Parameter	Value	Measurement Method
Mixing Rate/Frequency	Cultivated weekly with rototiller (weather permitting)	N/A
Moisture Content	10-12.8% by weight	N/A
pH	6.2 to 7.0	Saturated paste extraction
Residence Time	6 months	N/A
Temperature	Information not provided	N/A
Hydrocarbon Degradation	8-58%	Calculated - see Table 5
Nutrients and Other Soil Amendments	Cow manure C:N:P maintained at 100:2:1	Nitrogen measured using potassium chloride and water extractions
Conductivity	1.76 mmhos/cm	Saturated paste extraction
Sulfur	0.05%	N/A

N/A - Measurement method not reported for this parameter because resulting value not expected to vary among measurement procedures.

Timeline

A timeline for this application is shown in Table 4.

Table 4. Timeline [1, 2, 3, 22]

Start Date	End Date	Activity
1907	1985	Burlington Northern conducted wood preserving operations at the site
December 1982	-	Site placed on NPL
August 1985	October 1985	Construction of land treatment unit
May 1986	October 1994	Land treatment of contaminated soil and sludges
July 1995	August 1995	Cover placed over LTU

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards [1, 23]

A RCRA Part B permit for this site specified the following:

- Treatment of the soil and sludge so that the concentration of methylene chloride extractable (MCE) hydrocarbons and the sum of the concentrations for 17 PAHs in the treatment zone would not be greater than these values for non-visibly-impacted soils; and

- Detoxification of the treatment zone to "within Microtox® limits". However, no quantitative limits were specified in the permit.

The first specification corresponds to the following cleanup goals for treated soil and sludge:

- MCE Hydrocarbons: 21,000 mg/kg; and
- Total PAHs: 8,632 mg/kg.

Total PAHs were identified in this application as the sum of the concentrations for the following 17 PAHs:

- Naphthalene;
- Acenaphthylene;
- Acenaphthene;
- Fluorene;
- Phenanthrene;
- Anthracene;
- Fluoranthene;
- Pyrene;
- Benzo(a)anthracene;
- Chrysene;
- Benzo(b)fluoranthene;
- Benzo(k)fluoranthene;
- Benzo(e)pyrene;
- Benzo(a)pyrene;
- Indeno(123-cd)pyrene;
- Dibenzo(ah)anthracene; and
- Benzo(ghi)perylene.

In addition, the permit provided for the following contingency procedures if the LTU did not meet these cleanup goals at the end of the treatment period:

- Extend the closure period and continue operations;
- Extend the closure period and modify operations; and
- Place a cover over the treatment area to prevent infiltration of liquid through the treatment zone.

TREATENT SYSTEM PERFORMANCE (CONT.)

Additional Information on Goals [23]

In addition to the cleanup goals described above for treatment of soil and sludge, the following concentration limits were identified in the Consent Order as "action levels" for groundwater at Burlington Northern:

- 30 nanograms per liter (ng/L) for the sum of the following known or suspected carcinogenic PAHs and heterocycles:

  -- Benzo(a)anthracene;
  -- Benzo(b)fluoranthene;
  -- Benzo(j)fluoranthene;
  -- Benzo(k)fluoranthene;
  -- Benzo(a)pyrene;
  -- 7H-Dibenzo(c,g)carbazole;
  -- 5-Methylchrysene;
  -- Indeno(123-c,d)pyrene;
  -- Dibenzo(a,h)anthracene;
  -- Dibenzo(a,h)acridine;
  -- Dibenzo(a,j)acridine;
  -- Dibenzo(a,e)pyrene;
  -- Dibenzo(a,i)pyrene; and
  -- Dibenzo(a,l)pyrene.

- 300 ng/L for the sum of the following 22 non-carcinogenic PAHs and heterocycles:

  -- Indene;
  -- 2,3-Dihydroindence;
  -- Naphthalene;
  -- 1-Methylnaphthalene;
  -- 2-Methylnaphthalene;
  -- Biphenyl;
  -- Acenaphthylene;
  -- Acenaphthene;
  -- Fluorene;
  -- Phenanthrene;
  -- Anthracene;
  -- Fluoranthene;
  -- Pyrene;
  -- Benzo(h)fluoranthene;
  -- Benzo(e)pyrene;
  -- Perylene;
  -- Acridine;
  -- Carbazole;
  -- 2,3-Benzofuran;
  -- Benzo(b)thiophene;
  -- Dibenzothiophene; and
  -- Indole.

The following action levels for individual constituents in groundwater were also specified. However, these action levels were not required cleanup goals:

Acenaphthene	-	4,000 μg/L	Phenol (total)	-	4,000 μg/L
Anthracene	-	2,000 μg/L	2,4-Dimethylphenol	-	100 μg/L
Fluoranthene	-	300 μg/L	2,4-Dichlorophenol	-	20 μg/L
Fluorene	-	300 μg/L	2-Methylphenol	-	30 μg/L
Naphthalene	-	30 μg/L	Biphenyl	-	300 μg/L

TREATENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data

To assess LTU treatment performance, each lift of contaminated soil and sludge was sampled immediately after application and then monthly through the end of the treatment season. To facilitate sampling, the LTU was divided into three areas of approximately equal size. Each month, two sites were sampled in each of the three areas, resulting in six samples. The sample from each site consisted of a composite of at least three subsamples from that area. The samples were analyzed for MCE hydrocarbons and PAHs, and the results for each of these six samples were averaged. Tables 5 through 9 present the before treatment (from the beginning of each treatment season, after the new soil lift was applied in May or June), and after treatment (from the end of each season, in October or November). Analytical results for these samples from the nine treatment seasons are shown in Tables 5 through 9, as described below:

- Table 5 - Treatment Performance Data for MCE Hydrocarbons;
- Table 6 - Treatment Performance Data for Two-Ring PAHs;
- Table 7 - Treatment Performance Data for Three-Ring PAHs;
- Table 8 - Treatment Performance Data for Four- and Five-Ring PAHs; and
- Table 9 - Treatment Performance Data for Total PAHs.

Tables 5 through 9 also show the dates on which samples were collected, where available.

At the completion of the last treatment season (1994), samples were collected at four depths in the LTU to assess residual concentrations of MCE hydrocarbons and PAHs. These samples were also analyzed for Microtox® EC 50. Table 10 presents the results for these samples. For each of the four depths sampled, concentrations of MCE hydrocarbons, specific PAHs, and Microtox® EC 50 are presented for the 1994 treatment season (0-8 inches), 1990-1993 treatment seasons (8-32 inches), 1986-1989 treatment seasons (32-56 inches), and the soil layer immediately below the original layer of contaminated material (55-66 inches).

Table 11 summarizes analytical data for selected parameters in the leachate during treatment. The results are from grab samples collected from the treatment area drain tile leachate. More detailed data on leachate are presented in Appendix A. Data were collected for MCE hydrocarbons, 7 PAHs, and 5 acid extractable constituents in the leachate during the 9 treatment seasons.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Table 5. Treatment Performance Data for MCE Hydrocarbons [1, 2, 5, 6, 7, 8, 9]

	Before Treatment		After Treatment	
Treatment Season	Concentration (mg/kg)	Date Sample Collected	Concentration (mg/kg)	Date Sample Collected
1986	53,000	N/A	22,000	N/A
1987	67,000	05/20/87	48,000	10/09/87
1988	74,000	05/04/88	36,000	10/19/88
1989	83,000	05/11/89	47,000	10/24/89
1990	26,000	05/21/90	24,000	N/A
1991	53,000	N/A	28,000	10/27/91
1992	69,000	N/A	29,000	11/11/92
1993	89,000	05/07/93	38,000	10/18/93
1994	62,000	06/23/94	27,000	11/03/94
Average	64,000	-	33,000	-

N/A - Date sample collected is not available.

Table 6. Treatment Performance Data for Two-Ring PAHs [1, 2, 5, 6, 7, 8, 9]

	Before Treatment		After Treatment	
Treatment Season	Concentration (mg/kg)	Date Sample Collected	Concentration (mg/kg)	Date Sample Collected
1986	2,250	N/A	ND (120)	N/A
1987	2,848	05/20/87	140	10/09/87
1988	1,972	05/04/88	65	10/19/88
1989	2,749	05/11/89	ND (11)	10/24/89
1990	848	05/21/90	92	N/A
1991	1,319	N/A	3	10/27/91
1992	99	N/A	9	11/11/92
1993	3,269	05/07/93	108	10/18/93
1994	691	06/23/94	65	11/03/94
Average	1,783	-	68	-

N/A - Date sample collected is not available.
ND - Not detected; value in parentheses is the reported detection limit.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Table 7. Treatment Performance Data for Three-Ring PAHs [1, 2, 5, 6, 7, 8, 9]

Treatment Season	Before Treatment		After Treatment	
	Concentration (mg/kg)	Date Sample Collected	Concentration (mg/kg)	Date Sample Collected
1986	9,560	N/A	445	N/A
1987	8,750	05/20/87	774	10/09/87
1988	6,032	05/04/88	191	10/19/88
1989	2,989	05/11/89	448	10/24/89
1990	2,113	05/21/90	411	N/A
1991	2,423	N/A	291	10/27/91
1992	265	N/A	163	11/11/92
1993	5,927	05/07/93	401	10/18/93
1994	1,287	06/23/94	225	11/03/94
Average	4,372		372	

N/A - Date sample collected is not available.

Table 8. Treatment Performance Data for Four- and Five-Ring PAHs [1, 2, 5, 6, 7, 8, 9]

Treatment Season	Before Treatment		After Treatment	
	Concentration (mg/kg)	Date Sample Collected	Concentration (mg/kg)	Date Sample Collected
1986	4,350	N/A	1,330	N/A
1987	6,273	05/20/87	3,412	10/09/87
1988	4,927	05/04/88	2,889	10/19/88
1989	5,149	05/11/89	2,059	10/24/89
1990	3,047	05/21/90	772	N/A
1991	2,355	N/A	654	10/27/91
1992	262	N/A	392	11/11/92
1993	4,275	05/07/93	711	10/18/93
1994	1,566	06/23/94	505	11/03/94
Average	3,578		1,414	

N/A - Date sample collected is not available.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Table 9. Treatment Performance Data for Total PAHs [1, 2, 5, 6, 7, 8, 9]

Treatment Season	Before Treatment		After Treatment	
	Concentration (mg/kg)	Date Sample Collected	Concentration (mg/kg)	Date Sample Collected
1986	16,160	N/A	1,895	N/A
1987	17,871	05/20/87	4,326	10/09/87
1988	12,931	05/04/88	3,145	10/19/88
1989	10,887	05/11/89	2,518	10/24/89
1990	6,008	05/21/90	1,275	N/A
1991	6,097	N/A	948	10/27/91
1992	626	N/A	564	11/11/92
1993	13,471	05/07/93	1,220	10/18/93
1994	3,544	06/23/94	795	11/03/94
Average	9,733		1,854	

N/A - Date sample collected is not available.

Table 10. Residual Concentrations of MCE Hydrocarbons and PAHs in the LTU at Completion of Treatment (November 3, 1994) [1]

Parameters	Concentration (mg/kg)				
	Depth Sampled (Inches)				Treatment Goal[5]
	0-8[1]	8-32[2]	32-56[3]	56-66[4]	
MCE Hydrocarbons	26,900	24,800	25,300	450	21,000
Naphthalene	2.63	2.1	9.2	0	
Acenaphthylene	5.02	6.85	9.3	0.02	
Acenaphthene	57.48	37	31	0	
Total 2-Ring PAH	65.13	45.95	49.5	0.02	
Fluorene	23	22	36	0	
Phenanthrene	105	44	53	0.02	
Anthracene	97	62	110	0.13	
Total 3-Ring PAH	225	128	199	0.15	
Fluoranthene	189	112	95	0.07	
Pyrene	126	77	92	0.1	
Benzo(a)anthracene	32	36	33	0	
Chrysene	35	51	36	0	
Total 4-Ring PAH	382	276	256	0.17	
Benzo(b)fluoranthene	44	66	87	0.04	
Benzo(k)fluoranthene	20	17	32	0	
Benzo(e)pyrene	15.5	20.5	27.5	0.0275	

Table 10 (Continued)

Parameters	Concentration (mg/kg)				
	Depth Sampled (Inches)				Treatment Goal[5]
	0-8[1]	8-32[2]	32-56[3]	56-66[4]	
Benzo(a)pyrene	15.5	20.5	27.5	0.0275	
Indeno(123-cd)pyrene	12	17.6	22.2	0.13	
Dibenzo(ah)anthracene	4.5	5.8	9.3	0	
Benzo(ghi)perylene	12	11	21.2	0	
Total 5-Ring PAH	123.5	158.4	226.7	0.225	
Total PAHs	795.63	608.35	731.2	0.565	8,632
Microtox® EC 50 (5 min, 15°C)	15.3	8.2	4.9	70	--[6]

[1]The 0"-8" depth corresponds to the 1994 treatment season.
[2]The 8"-32" depth corresponds to the 1990 to 1993 treatment seasons.
[3]The 32"-56" depth corresponds to the 1986 to 1989 treatment seasons.
[4]The 56"-66" depth corresponds to the soil layer immediately below the original layer of contaminated material.
[5]Treatment goal was established for total PAHs only; no treatment goal has been established for individual PAH constituents or groups of constituents (e.g., 2-Ring PAHs) in soils.
[6]No quantitative treatment goal has been established for Microtox®.

Table 11. Summary of Concentration Data for Selected Parameters in Leachate During Treatment [1]

Parameter	Units	Groundwater Action Level	Range of Concentrations Measured	Number of Sampling Events
MCE Hydrocarbons	mg/L	Not specified	ND - 600	36
PAHs				
Acenaphthene	μg/L	4,000	ND - 18	36
Acenaphthylene	μg/L	Not specified	ND - 13	36
Anthracene	μg/L	2,000	ND - 52	36
Fluoranthene	μg/L	300	ND - 5.7	36
Fluorene	μg/L	300	ND - 73.28	36
Naphthalene	μg/L	30	ND - 590	36
Phenanthrene	μg/L	Not specified	ND - 18	36
Acid Extractables				
Phenol	μg/L	4,000	ND - 5.3	36
2,4-Dimethylphenol	μg/L	100	ND - 100	36
2,4-Dichlorophenol	μg/L	20	ND - 22	36
2-Methylphenol	μg/L	30	ND - 87	36
4-Methylphenol	μg/L	Not specified	ND - 48	36

ND - Not detected; detection limit not provided in available references.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment

Soil/Sludge:

The treatment performance data presented in Tables 5 and 9 show that the cleanup goal for total PAHs was achieved for all 9 treatment seasons. However, the cleanup goal for MCE hydrocarbons was not met in any of the 9 treatment seasons. The concentrations of MCE hydrocarbons in soil before treatment ranged from 26,000 to 89,000 mg/kg, and from 22,000 to 48,000 mg/kg in soil after treatment, all of which are greater than the cleanup goal of 21,000 mg/kg. The median value for MCE hydrocarbons in soil after treatment was 29,000 mg/kg, and the mean (average) value was 33,000 mg/kg. Because the cleanup goal for MCE hydrocarbons was not met at the end of the treatment period, Burlington Northern implemented the contingency procedure of placing a cover over the treatment area to prevent infiltration of liquid through the treatment zone.

Total PAHs in soil before treatment ranged from 626 to 17,871 mg/kg, and from 564 to 4,326 mg/kg in soil after treatment. The concentrations of total PAHs in the soil after treatment was less than the cleanup goal of 8,632 mg/kg for all 9 treatment seasons. The median value for total PAHs in soil after treatment was 1,275 mg/kg, and the mean (average) value was 1,854 mg/kg.

The residual concentrations of MCE hydrocarbons and PAHs (November 1994 samples) did not vary substantially with depth in the LTU among the treatment seasons, as shown in Table 10. The concentrations of MCE hydrocarbons varied less than 10% with depth through the top 56 inches of the LTU. The concentrations of total PAHs varied approximately 26% with depth through the top 56 inches of the LTU.

In addition, data on residual concentrations show that contaminants in the soils treated in the LTU did not migrate to the uncontaminated soil layer below the LTU. After treatment, the concentrations of MCE hydrocarbons, total PAHs, and Microtox® EC 50 in the uncontaminated soil layer in the LTU immediately below the original layer of contaminated material (the 56- to 66-inch layer) were substantially lower than in the layers of treated soil (the 0- to 56-inch layers).

Analytical data on treatment performance for individual PAH constituents show that treatment efficiency (measured as a percent reduction in average concentration from before treatment to after treatment) decreased with increasing number of ring structures in the PAH molecule. For example, as shown in Tables 6, 7, and 8, two-ring PAHs were reduced an average of 96%, three-ring PAHs were reduced an average of 92%, and four- and five-ring PAHs were reduced an average of 60%. Two-ring PAHs were reduced to concentrations below analytical detection limits for two of the nine treatment seasons.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (cont.)

Leachate:

Analytical data for leachate collected during treatment were compared with the groundwater action levels to evaluate the quality of the leachate. These data for the 36 sampling episodes over a 9-year period are presented in Appendix A and summarized in Table 11. With the exception of naphthalene and 2-methylphenol, the range of concentrations measured in the leachate were below the groundwater action levels. Naphthalene was measured as high as 590 μg/L (versus an action level of 30 μg/L) and 2-methylphenol was measured as high as 87 μg/L (versus an action level of 30 μg/L).

Performance Data Completeness

Data are available for characterizing specific constituents, groups of constituents, and indicator parameters in the soil before and after treatment for each of 9 treatment seasons in the LTU. In addition, data are available on leachate quality during the 9 treatment seasons, and on general operating conditions during the treatment operation.

Performance Data Quality

Limited information is provided in the available references on the types of QA/QC protocols used and the QA/QC data that are available concerning this effort. No exceptions to protocol or limits were identified in this information. In addition, no information is available on the specific steps involved with the MCE hydrocarbon analysis. [5]

During the earlier treatment seasons (1986-1990), total hydrocarbons were analyzed using a benzene extraction procedure. The benzene extractable hydrocarbons procedure was based on a modification of Procedure 503C in Standard Methods for Examination of Water and Wastewaters, 15th edition, for measurement of oil and grease by soxhlet extraction. For this application, benzene was substituted for freon as the extraction solvent. The benzene extraction procedure was replaced with a methylene chloride extraction procedure for the latter treatment seasons (1991-1994). According to Burlington Northern, this revision to the analytical procedure is not expected to have had a significant impact on the quality of the analytical results, and results for total hydrocarbons are identified throughout this report as MCE hydrocarbons. [5, 9]

TREATMENT SYSTEM COST

Procurement Process [21]

The land treatment application at Burlington Northern was a PRP-lead project, and Burlington Northern selected ReTeC as the treatment vendor for the project. (The PRP point of contact is Dave Seep, (817) 333-1946.) No additional information is provided in the available references on the process used to procure ReTeC for this remediation project, or on the competitive nature of the procurement.

Treatment System Cost

This is a PRP-lead remediation, and EPA does not have information on the actual costs incurred for this application. No information is provided in the available references on actual treatment system costs, including costs for before-treatment activities (e.g., site work), activities directly attributed to treatment (e.g., system design, construction, and operation), or after-treatment activities, if any. In addition, no information is provided in the available references on actual costs per unit (e.g., ton, cubic yard) of soil treated.

Vendor Input

No information was provided by the vendor on site-specific factors that affect project costs for similar land treatment applications.

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- The land treatment application at Burlington Northern was PRP-lead, and no information on actual costs incurred (before-treatment, treatment, or after-treatment) is provided in the available references. In addition, no information is provided on unit costs (e.g., costs per cubic yard of soil and sludge treated) for this application.

Performance Observations and Lessons Learned

- The cleanup goal for total PAHs was met in this application. The concentrations of total PAHs was reduced in the LTU from before treatment levels ranging from 626 to 17,871 mg/kg to after treatment levels ranging from 564 to 4,326 mg/kg during the 9 treatment seasons. The concentrations in the soil after treatment were less than the cleanup goal of 8,632 mg/kg for all 9 treatment seasons.

- The concentrations of methylene chloride extractable (MCE) hydrocarbons were reduced in the LTU from before treatment levels ranging from 26,000 to 89,000 mg/kg to after treatment levels ranging from 22,000 to 48,000 mg/kg during the 9 treatment seasons. These values are all greater than the cleanup goal for MCE hydrocarbons of 21,000 mg/kg, and because of this, Burlington Northern implemented a contingency procedure of placing a cover over the LTU based on a permit provision.

- Microtox® analysis showed an EC 50 (5 min, 15°C) residual toxicity of 4.9-15.3 in the treated soil at the conclusion of treatment. However, no quantitative cleanup goal was specified for this parameter.

- Residual sampling of the layer immediately below the original layer of contaminated material showed that the soil contaminants did not migrate downward in the soil to below the treated soil during the 9 treatment seasons. The concentrations of MCE hydrocarbons and total PAHs, and the Microtox® EC 50 value, were substantially lower in the soil layer in the LTU immediately below the original layer of contaminated material (the 56- to 66-inch layer) than in the layers of treated soil (the 0- to 56-inch layers) at the conclusion of treatment.

- The residual concentrations of MCE hydrocarbons and PAHs at the completion of treatment did not vary substantially with depth in the LTU among the treatment seasons. The concentrations of MCE hydrocarbons varied less than 10% with depth through the top 56 inches of the LTU. The concentrations of total PAHs varied approximately 26% with depth through the top 56 inches of the LTU.

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Performance Observations and Lessons Learned (cont.)

- Treatment efficiency (measured as a percent reduction in average concentration from before treatment to after treatment) decreased with increasing number of ring structures in the PAH molecule. Two-ring PAHs were reduced an average of 96%, three-ring PAHs were reduced an average of 92%, and four- and five-ring PAHs were reduced an average of 60%. Two-ring PAHs were reduced to concentrations below analytical detection limits for two of the nine treatment seasons.

- With the exception of naphthalene and 2-methylphenol, the range of concentrations measured in the leachate were below the groundwater action levels. Naphthalene was measured as high as 590 μg/L (versus an action level of 30 μg/L) and 2-methylphenol was measured as high as 87 μg/L (versus an action level of 30 μg/L).

Other Observations and Lessons Learned

- Burlington Northern placed a cover over the LTU during July and August 1995. EPA reviewed the design documents and approved the design prior to construction. The closure was approved by EPA on January 8, 1996.

- The vendor indicated that the reason MCE hydrocarbons were not treated to below the cleanup level is because a "plateau effect" limited the extent of biodegradation of total extractable hydrocarbons. Although a treatability study indicated otherwise, full-scale performance data indicated that total extractable hydrocarbons (as MCE) were biodegraded only to a level slightly higher than the target treatment goal.

- The vendor indicated that the higher than expected MCE hydrocarbon levels and residual toxicity in the soil at the conclusion of treatment did not reflect a significant threat to human health or the environment, and expressed their belief that the residual creosote constituents in the soil were "biostabilized." The vendor suggested performance standards based on concentrations of specific constituents of interest would be more appropriate at other sites, instead of those based on MCE hydrocarbons or Microtox analyses.

- While this application did not meet the MCE hydrocarbon cleanup goal, MCE hydrocarbons are no longer typically used as a performance measure for land treatment systems.

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21. Memorandum from A. Rutter, RPM, to L. Fiedler, U.S. EPA/TIO; Burlington Northern Site; February 2, 1996.

22. Letter from M. Salisbury, ReTeC, to L. Fiedler, U.S. EPA; "Comments on Draft Remediation Case Study Report, Land Treatment at the Burlington Northern Superfund Site, Brainerd/Baxter, Minnesota;" February 6, 1996.

23. Remedial Action Report for the BNSF Former Tie Treating Plant, Brainerd, Minnesota; prepared for Burlington Northern Santa Fe Railroad; prepared by Remediation Technologies, Inc.; November 1995.

Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Radian International under EPA Contract No. 68-W3-0001 and U.S. Army Corps of Engineers Contract No. DACA45-96-D-0016.

Appendix A. Table A-1. Concentrations of Selected Parameters in Leachate During Treatment [1]

Parameter	Units	Groundwater Action Level	Sampling Date				
			06/17/86	08/07/86	10/14/86	05/20/87	08/21/87
MCE Hydrocarbons	mg/L	--	3.4	7.9	2.5	1.5	19
PAHs							
Acenaphthene	µg/L	4,000	ND	4	3	ND	4
Acenaphthylene	µg/L	--	ND	ND	ND	ND	3
Anthracene	µg/L	2,000	ND	ND	ND	ND	14
Fluoranthene	µg/L	300	ND	2	1	ND	2
Fluorene	µg/L	300	ND	ND	ND	ND	2
Naphthalene	µg/L	30	ND	ND	ND	ND	2
Phenanthrene	µg/L	--	ND	ND	ND	ND	ND
TOTAL PAH	µg/L		0	6	4	0	27
Acid Extractables							
Phenol	µg/L	4,000	ND	ND	ND	ND	5.3
2,4-Dimethylphenol	µg/L	100	ND	ND	ND	ND	6.5
2,4-Dichlorophenol	µg/L	20	ND	ND	ND	ND	ND
2-Methylphenol	µg/L	30	ND	ND	ND	ND	ND
4-Methylphenol	µg/L	--	ND	ND	ND	ND	ND

Parameter	Units	Groundwater Action Level	Sampling Date						
			North Drain 05/04/88	South Drain 05/04/88	North Drain 10/19/88	South Drain 10/19/88	05/03/89	11/16/89	05/10/90
MCE Hydrocarbons	mg/L	--	9	8	144	144	600	20	10
PAHs									
Acenaphthene	µg/L	4,000	2	3	2	2	ND	ND	ND
Acenaphthylene	µg/L	--	ND	ND	ND	ND	ND	ND	ND
Anthracene	µg/L	2,000	ND	ND	ND	1	ND	ND	ND
Fluoranthene	µg/L	300	1	2	ND	ND	ND	ND	ND
Fluorene	µg/L	300	1	ND	ND	ND	73.28	ND	ND
Naphthalene	µg/L	30	ND	ND	3	5	ND	590	ND
Phenanthrene	µg/L	--	ND	ND	ND	ND	ND	ND	ND
TOTAL PAH	µg/L		4	5	5	8	73.28	590	0
Acid Extractables									
Phenol	µg/L	4,000	ND	ND	ND	ND	ND	ND	ND
2,4-Dimethylphenol	µg/L	100	ND	ND	ND	ND	ND	ND	ND
2,4-Dichlorophenol	µg/L	20	ND	ND	ND	ND	ND	ND	22
2-Methylphenol	µg/L	30	ND	ND	ND	ND	ND	ND	ND
4-Methylphenol	µg/L	--	ND	ND	ND	ND	ND	ND	ND

ND - Not detected; detection limit not provided in available references.

Table A-1 (Continued)

Parameter	Units	Groundwater Action Level	Sampling Date 05/21/91	06/26/91	07/25/91	08/20/91	09/19/91	10/27/91
MCE Hydrocarbons	mg/L	--	ND	20	20	20	ND	ND
PAHs								
Acenaphthene	µg/L	4,000	ND	6	7	6	14	18
Acenaphthylene	µg/L	--	ND	ND	ND	ND	5	ND
Anthracene	µg/L	2,000	ND	9	ND	ND	16	13
Fluoranthene	µg/L	300	ND	ND	ND	ND	ND	ND
Fluorene	µg/L	300	ND	ND	ND	ND	6	ND
Naphthalene	µg/L	30	14	11	18	16	29	ND
Phenanthrene	µg/L	--	ND	ND	ND	ND	18	ND
TOTAL PAH	µg/L		14	26	25	22	88	31
Acid Extractables								
Phenol	µg/L	4,000	ND	ND	ND	ND	ND	ND
2,4-Dimethylphenol	µg/L	100	30	ND	24	ND	ND	20
2,4-Dichlorophenol	µg/L	20	ND	ND	ND	ND	ND	ND
2-Methylphenol	µg/L	30	59	12	87	33	57	ND
4-Methylphenol	µg/L	--	ND	ND	9	ND	48	ND

Parameter	Units	Groundwater Action Level	Sampling Date 05/21/92	06/29/92	07/21/92	08/20/92	09/17/92	11/11/92
MCE Hydrocarbons	mg/L	--	14	29	ND	ND	116	51
PAHs								
Acenaphthene	µg/L	4,000	ND	ND	ND	ND	ND	ND
Acenaphthylene	µg/L	--	ND	ND	ND	ND	ND	ND
Anthracene	µg/L	2,000	ND	ND	ND	ND	ND	20
Fluoranthene	µg/L	300	ND	ND	ND	ND	ND	ND
Fluorene	µg/L	300	ND	ND	ND	ND	ND	ND
Naphthalene	µg/L	30	ND	ND	ND	ND	ND	ND
Phenanthrene	µg/L	--	ND	ND	ND	ND	ND	ND
TOTAL PAH	µg/L		0	0	0	0	0	20
Acid Extractables								
Phenol	µg/L	4,000	ND	ND	ND	ND	ND	ND
2,4-Dimethylphenol	µg/L	100	ND	25	72	100	62	ND
2,4-Dichlorophenol	µg/L	20	ND	ND	ND	ND	ND	ND
2-Methylphenol	µg/L	30	ND	ND	ND	ND	ND	ND
4-Methylphenol	µg/L	--	ND	ND	ND	ND	ND	ND

ND - Not detected; detection limit not provided in available references.

Table A-1 (Continued)

Parameter	Units	Groundwater Action Level	Sampling Date 05/07/93	06/21/93	07/26/93	08/23/93	09/20/93	10/18/93
MCE Hydrocarbons	mg/L	--	110	123	21	96	153	15
PAHs								
Acenaphthene	µg/L	4,000	ND	ND	ND	ND	13	18
Acenaphthylene	µg/L	--	ND	ND	ND	ND	ND	13
Anthracene	µg/L	2,000	ND	ND	ND	ND	13	19
Fluoranthene	µg/L	300	ND	ND	ND	ND	ND	ND
Fluorene	µg/L	300	ND	ND	ND	ND	ND	ND
Naphthalene	µg/L	30	13	ND	ND	43	29	43
Phenanthrene	µg/L	--	ND	ND	ND	ND	ND	8
TOTAL PAH	µg/L		13	0	0	43	55	101
Acid Extractables								
Phenol	µg/L	4,000	ND	ND	ND	ND	ND	ND
2,4-Dimethylphenol	µg/L	100	24	ND	ND	48	50	73
2,4-Dichlorophenol	µg/L	20	ND	ND	ND	ND	ND	ND
2-Methylphenol	µg/L	30	ND	ND	ND	ND	32	ND
4-Methylphenol	µg/L	--	ND	ND	ND	ND	6	ND

Parameter	Units	Groundwater Action Level	Sampling Date 06/23/94	07/26/94	08/15/94	09/07/94	10/13/94	11/03/94
MCE Hydrocarbons	mg/L	--	ND	ND	11	ND	1	ND
PAHs								
Acenaphthene	µg/L	4,000	11	ND	8	11	ND	17
Acenaphthylene	µg/L	--	9	ND	3	6	ND	7.8
Anthracene	µg/L	2,000	21	ND	13	18	52	21
Fluoranthene	µg/L	300	ND	ND	ND	ND	ND	5.7
Fluorene	µg/L	300	ND	ND	ND	ND	ND	ND
Naphthalene	µg/L	30	27	15	16	32	52	34
Phenanthrene	µg/L	--	13	ND	5	ND	ND	ND
TOTAL PAH	µg/L		81	15	45	67	104	85.5
Acid Extractables								
Phenol	µg/L	4,000	ND	ND	ND	ND	ND	ND
2,4-Dimethylphenol	µg/L	100	39	27	28	44	64	47
2,4-Dichlorophenol	µg/L	20	ND	ND	ND	ND	ND	ND
2-Methylphenol	µg/L	30	76	ND	ND	ND	ND	34
4-Methylphenol	µg/L	--	ND	ND	ND	ND	ND	10

ND - Not detected; detection limit not provided in available references.

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

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.

COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for a composting application at the Dubose Oil Products Co. Superfund site, in Cantonment, Florida. Composting was used at the Dubose site to treat soil contaminated with polynuclear aromatic hydrocarbons (PAHs), pentachlorophenol (PCP), and volatile organic compounds (VOCs), including benzene, xylene, trichloroethene (TCE), and 1,2-dichloroethene (DCE). The specific PAHs of interest at Dubose were acenaphthylene, acenaphthene, anthracene, benzo(a)anthracene, benzo(b and k)fluoranthenes, benzo(a)pyrene, benzo(ghi)perylene, chrysene, dibenz(a,h)anthracene, fluorene, fluoranthene, indeno(1,2,3)pyrene, naphthalene, phenanthrene, pyrene, and 2-methylnaphthalene.

The Dubose 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 (total) at concentrations ranging from 0.578 to 367 mg/kg, 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. The ROD specified treatment of contaminated soil using composting and identified numerical soil cleanup goals and leachate discharge standards for the site. Composting was selected 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 and samples would be more representative. Composting was also believed to be approximately equal in cost to in situ biological treatment. Soil cleanup goals included PAHs (total) - 50 mg/kg, PCP - 50 mg/kg, benzene - 10 mg/kg, xylenes (total) - 1.5 mg/kg, TCE - 0.05 mg/kg, and DCE - 0.07 mg/kg. Leachate discharge standards ranged from 1 to 50 μg/L for the target constituents/parameters.

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. Soil was aerated to maintain a pore space oxygen content of approximately 20 percent, and inoculum was added over a period of two days (typically), until the entire surface area of the soil was moistened. A moisture content of approximately 15% and a carbon:nitrogen:phosphorus ratio of 120:10:2 was maintained during the application. Off-gasses collected by the aeration equipment were treated using granular activated carbon (GAC) adsorbers prior to discharge to the atmosphere. Composting activities were performed from May to November 1993, and site restoration activities were completed by August 1996.

Soil sampling and analysis were performed for each of 359 grids of soil treated, including analysis for PAHs (total), PCP, and specific VOCs. Additional sampling and analysis were performed for leachate contaminants, and for monitoring of contaminants in the ambient air. All soil grids met the soil cleanup

EXECUTIVE SUMMARY (CONT.)

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 PAHs in this application was bioremediation; however, volatilization was identified as the primary mechanism for removal of VOCs, either in handling or through the aeration system. In addition, PAHs and VOCs were not measured in ambient air monitors at levels greater than their levels of concern for the application.

Actual costs of $7,736,700 were reported by the PRP Steering Committee's oversight contractor for this application, including approximately $2.5 million for before-treatment activities and $5.25 million for activities directly attributed to treatment. The $5.25 million expended for activities directly attributed to treatment corresponds to $266 per ton of soil treated (19,705 tons). This cost is relatively high because of the relatively large quantity of soil excavated (58,559 tons) but not further treated compared with the amount of soil treated. Unit costs based on the amount of soil excavated would be approximately one-third of $266, or $90 per ton of soil excavated. The application at Dubose was PRP-lead, and no information is provided in the available references on the portion of the $5.25 million cost that represents activities for excavation of less-contaminated soil that did not require further treatment in this application.

SITE INFORMATION

Identifying Information:

Dubose Oil Products Co. Superfund Site
Cantonment, Florida
CERCLIS # FLD000833368
Action Memorandum Date: March 29, 1990

Treatment Application:

Type of Action: Remedial
Treatability Study Associated with Application? Yes (See discussion under remedy selection)
EPA SITE Program Test Associated with Application? No
Period of Operation: November 1993 - September 1994
Quantity of Material Treated During Application: 19,705 tons of soil [31]

Background

Historical Activity that Contributed to Contamination at the Site: Waste storage, treatment, recycling and disposal

Corresponding SIC Code: 4953 W (Waste processing facility, miscellaneous)

Waste Management Practice that Contributed to Contamination: Waste Treatment Plant

Site History: [1, 31]

The 20-acre Dubose Oil Products Company Superfund site (Dubose, or DOPC) is a former waste storage, treatment, recycling, and disposal facility located approximately two miles west of Cantonment, Florida, as shown in Figure 1. Site operations began in 1979, and included thermal treatment of waste oil, petroleum refining wastes, oil-based solvents, and wood treatment wastes; steam heating of spent iron and steel pickle liquors; and rock salt filtration of waste diesel fuel.

Site operations ceased in 1981, and the site owner began closure of the site at that time. Closure activities included excavation of buried drums, operation of an aeration system to remediate on-site drainage ponds, and movement of contaminated material with heavy equipment. In March 1982, the Florida Department of Environmental Regulation (now called the Florida Department of Environmental Protection - FDEP) conducted an Interim Status Standards Compliance Inspection at the site. In April and May 1982, EPA and FDEP sampled the site and found buried metal objects, contaminated springs and leachate seeps, and an oil sheen on the North Pond.

In November 1984, FDEP directed an outside contractor (OH Materials Company) to excavate an on-site pond and fill it with contaminated soils and sediments. Between November 1984 and

SITE INFORMATION (CONT.)

Background (cont.)

May 1985, the contractor excavated an area of the site and lined it with a 36 millimeter (mm) PVC liner. The depression was filled with site soils to approximately 20 feet above surrounding grade and covered with a 30 mil PVC cover. An estimated 38,000 cubic yards of soil was placed in the former pond area, referred to as the soil "vault". The vault was approximately 170 feet long by 170 feet wide by 35 feet deep.

In October 1987, a consent agreement was signed by FDEP and the DOPC potentially responsible party (PRP) steering committee (DOPCSC). Following the consent agreement, the PRP Steering Committee tasked a consultant (Engineering-Science) to conduct a remedial investigation/ feasibility study (RI/FS) for the site.

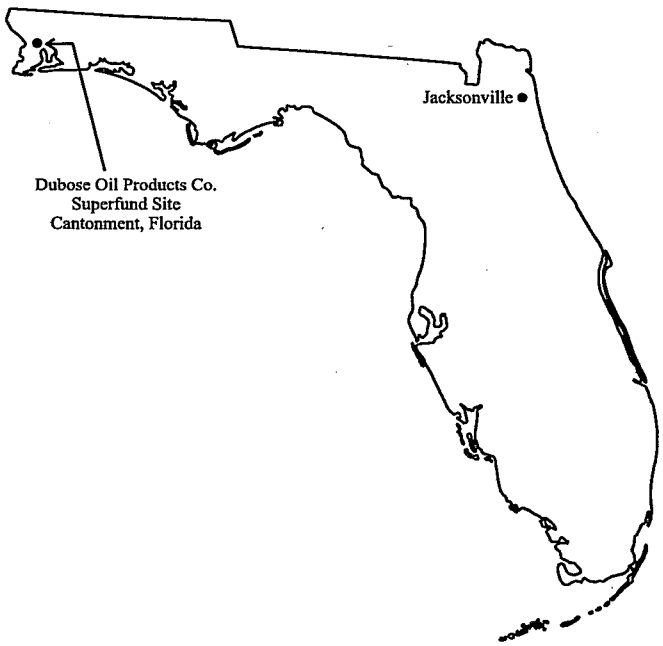

Figure 1. Site Location

The RI was conducted in 1988, and revealed contamination above health-based levels in the vault soils, shallow aquifer beneath the site, on-site surface water, and sediment. The RI identified the primary contaminants of concern in the soil, groundwater, surface water, and sediment as volatile organic compounds (VOCs) including trichloroethene, benzene, toluene, and xylenes and semivolatile organic compounds including polynuclear aromatic hydrocarbons (PAHs) and phenols (e.g., pentachlorophenol, or PCP).

Regulatory Context: [1] A Record of Decision (ROD) was signed for this site in March 1990. The ROD identified remedial actions for this site, including:

- Excavation of the top 20 feet of vault soils, shown in the RI to be uncontaminated, and placement of those soils into a ravine area at the site;
- Transformation of a hog barn area into a process area, and installation of a batch bioremediation (composting) system at that location;

SITE INFORMATION (CONT.)

Background (cont.)

- Excavation of the remainder of the vault soils in separate batches, treatment of the batches using bioremediation, followed by disposal in the ravine area;
- Drainage and filling of the on-site ponds;
- Placement of a 2-foot topsoil layer over the ravine and former pond area, grading and vegetation;
- Installation of surface water runoff controls to accommodate seasonal precipitation;
- Groundwater monitoring;
- Additional soil sampling during remedial design to confirm location of "hot spots" of contaminated soil outside of the vault; and
- Deed restrictions to preclude inappropriate future use.

The ROD identified numerical soil cleanup goals and leachate discharge standards for this site (see discussion under treatment system performance).

Remedy Selection: [1, 30, 31] Composting was selected as the remedy for the Dubose site from 10 alternatives. The ROD indicated that composting would be easier to control and more reliable than in situ biological treatment. In addition, the ROD indicated that monitoring the effectiveness of composting would be easier than for in situ treatment, because the mixing and turning of soil piles will make the soil more homogeneous and soil grab samples more representative. The ROD also indicated that composting would be approximately equal in cost to in situ biological treatment.

As part of the RI, Engineering Science was tasked to conduct bench-scale treatability studies on the effectiveness of biological remediation for on-site soils. Engineering Science conducted the following four types of treatability studies using contaminated soil from the containment vault: in-situ column, serum bottle, biometer, and mesocosm experiments. The mesocosm experiments showed that composting could be used to reduce the concentrations of all contaminants of concern at Dubose. [33]

Pilot-scale treatability testing was attempted six times during this project. However, soil excavated for pilot-scale tests was found to contain too low a concentration of target compounds, and no pilot-scale testing was completed.

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Management: PRP Lead
Oversight: EPA

Remedial Project Manager:

Mark Fite
U.S. EPA, Region 4
Atlanta Federal Center
100 Alabama St., S.W.
Atlanta, GA 30303
(404) 562-8927

PRP Steering Committee Oversight Contractor:

Kenneth Stockwell
Parsons Engineering Science, Inc.
57 Executive Park South, N.E., Suite 500
Atlanta, GA 30329-2265
(404) 235-2351

Treatment Vendor:

David Price/Garland Long
Waste Abatement Technology, L.P. (WATEC)
1300 Williams Drive
Marietta, GA 30066
(770) 427-1947

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: soil (ex situ)

Contaminant Characterization

Primary Contaminant Groups: organic compounds - volatiles, halogenated; volatiles, nonhalogenated (BTEX); semivolatiles, halogenated and semivolatiles, nonhalogenated (PAHs)

During the RI, analyses of 278 soil and sediment samples were made to determine the nature and extent of contamination in the DOPC vault. Analysis of materials in the vault indicated a general stratification of contaminants, with the highest concentration of volatile and semivolatile organic compounds present at 25-30 feet below the top of the vault. Table 1 shows the range of contaminants measured in the soil vault during the RI. In this application, total PAHs were defined as the sum of the following 17 constituents: acenaphthene, acenaphthylene, anthracene benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, Benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, pyrene, and 2-methylnaphthalane. [31]

Table 1. Range of Contaminants Measured in Soil Vault During RI [31]

Contaminant/Parameter	Range of Concentrations (mg/kg)
VOCs	0.022 - 38.27
Total PAHs	0.578 - 122.4
PCP	0.058 - 51

In addition, analyses of soils outside the vault were performed, and several small areas of contaminated soil were characterized, including areas in the western berm of the vault and an on-site silo. The maximum total PAH concentration measured in the soils outside the vault was 367 mg/kg. [6, 31] Figure 2 shows the location of the soil vault, western berm and silo area "hot spots" at the DOPC site.

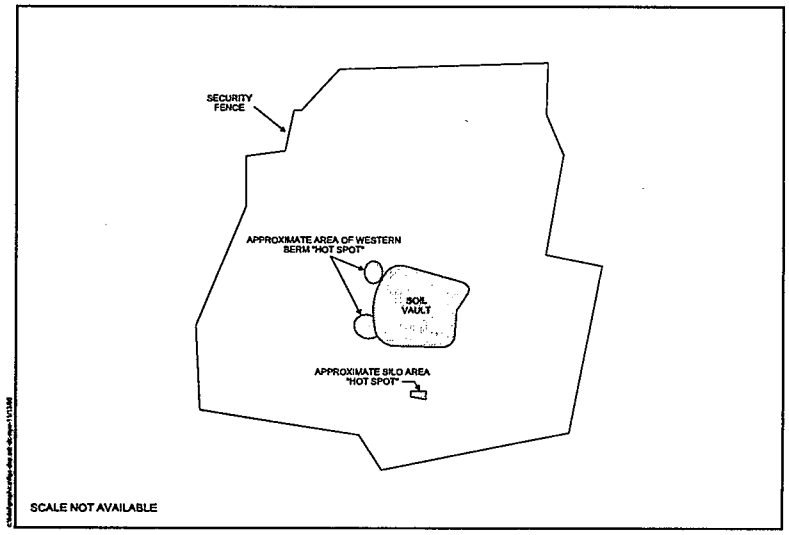

Figure 2. Location of Soil Vault and Hot Spots at DOPC Site [6]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Cost or Performance

The major matrix characteristics affecting cost or performance for this technology and the values measured for each are shown in Table 2.

Table 2. Matrix Characteristics [17]

Parameter	Value	Measurement Method
Soil Classification	Not provided	-
Clay Content and/or Particle Size Distribution	Not provided	-
pH	6.9 to 7.9	N/A
Total Petroleum Hydrocarbons	300 - 600 mg/kg	N/A
Moisture Content	8%	N/A

N/A - Measurement method not reported for this parameter because resulting value not expected to vary among measurement methods.

Although detailed soil classifications and particle size distribution information is not provided in the available references, the RPM indicated the soil was a Lakeland loamy sand. [32]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology Type: Composting

Supplemental Treatment Technology Type:

Post-treatment (air) - carbon adsorption; post-treatment (water) - chemical, filtration

Compost System Description and Operation

The composting system used at DOPC 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. Soil was piled approximately 4.0 to 4.25 feet deep in the treatment structure, and ambient air was drawn downward through the soil pile. A soil oxygen content of approximately 20% was maintained for this application. The inoculum solution was prepared using native soil microbes, and sprayed over the soil pile using a fire hose. Soil moisture was maintained at approximately 15%.

Figure 3 shows the layout of the major equipment at the site, including the location of the soil disposal area.

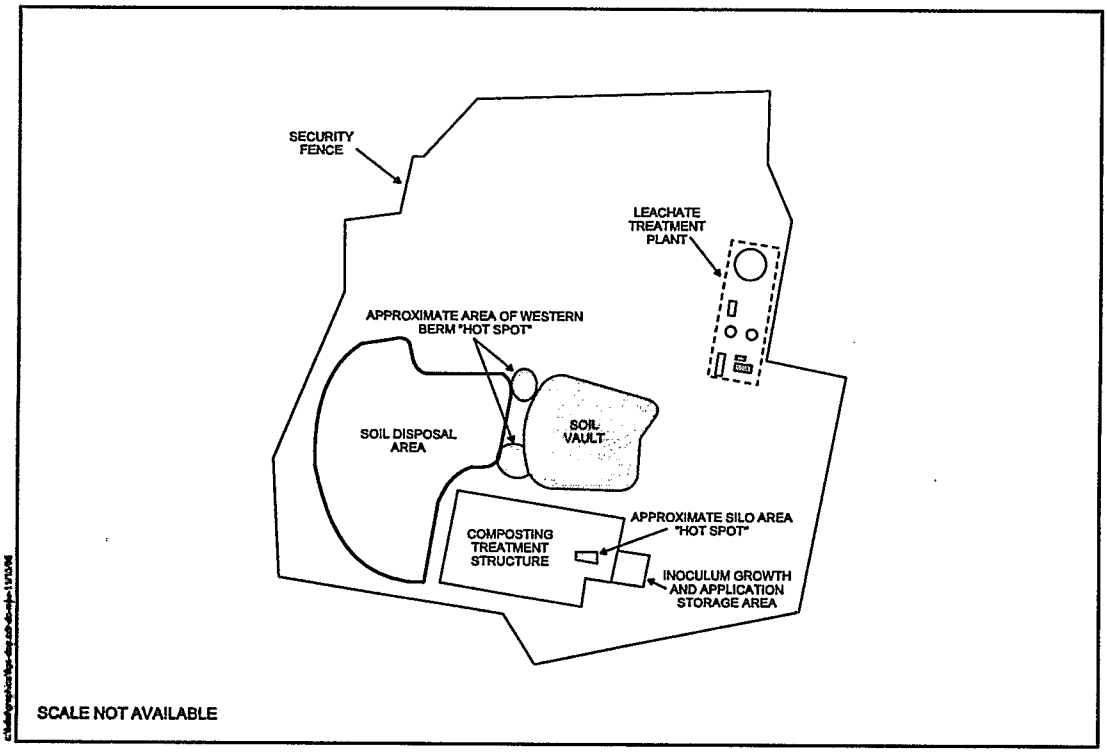

Figure 3. Layout of Major Equipment at DOPC [6]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Compost System Description and Operation (cont.)

System Design

Treatment Structure [17]

The treatment structure used at DOPC was a 33,000 square foot modular pre-engineered building (approximately 220 by 150 feet) that included three separate units (bays) positioned side by side. The structure was an aluminum I-beam frame structure with reinforced PVC fabric tensioned between the beans. Figure 4 shows a side view of the treatment structure. This structure was leased from Sprung Instant Structures of Fontana, California.

The floor of the structure was covered with a continuous 40 mm low density polyethylene (LDPE) liner which was anchored on top of a continuous 4 foot high wall around the facility. The wall inside of the structure was made of pressure treated lumber reinforced with welded wire mesh.

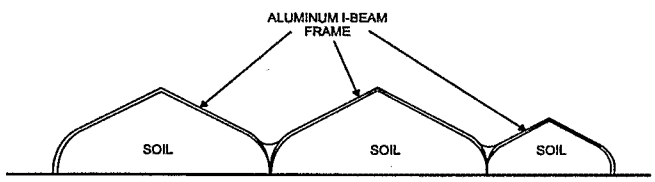

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Figure 4. Side View of Treatment Structure [17]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Compost System Description and Operation (cont.)

Leachate Collection System [17]

A leachate collection system was used to collect leachate generated from rainwater which blew in from the sides of the open end structure, from excess inoculum mixture which leached out of the soil, and from excess water draining from wet soil placed in the treatment structure.

The treatment structure was designed to incline east at a slope of 1%, and north at a slope of 1%, such that leachate would collect at the northeast corner of the structure. To assist in leachate collection, a composite drainage material was installed on top of the LDPE liner, consisting of a high density polyethylene (HDPE) capillary grid with a continuous 6 ounce non-woven geotextile attached to both sides. The geotextile acted as a fabric filter to keep solids out of the capillary grid. Eighteen (18) inches of filter sand were placed on top of the composite drainage materials to protect the liner and help leachate to drain to the collection system.

At the north end of the facility, a 2 foot deep by 2 foot wide leachate collection trench was installed. This trench was filled with number 68 stone, and transported leachate by gravity along the slope to the east end of the facility. Leachate was discharged from the trench to a concrete sump, located outside of the structure, and from there pumped to an on-site wastewater treatment system.

Aeration System [17, 32]

The aeration system used at DOPC, shown in Figure 5, pulled air through the soil placed inside the treatment structure, and consisted of pipes and valves, a moisture separator, a blower unit, and two vapor phase carbon vessels. This system also extracted VOCs from the soil.

Approximately 3,000 feet of aeration piping were installed throughout the treatment structure on top of the composite drainage mat, and below the 18 inches of filter sand, as shown in Figure 6. The pipes were 4-inch diameter perforated 3034 PVC wrapped in polyester pipe sock, and spaced approximately 10 inches apart.

The blower unit used at DOPC was a 15 horsepower Rotron EN12 explosion proof regenerative blower, which pulled approximately 300 cubic feet per minute (cfm) of air at a vacuum at 80 to 90 inches of water.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Compost System Description and Operation (cont.)

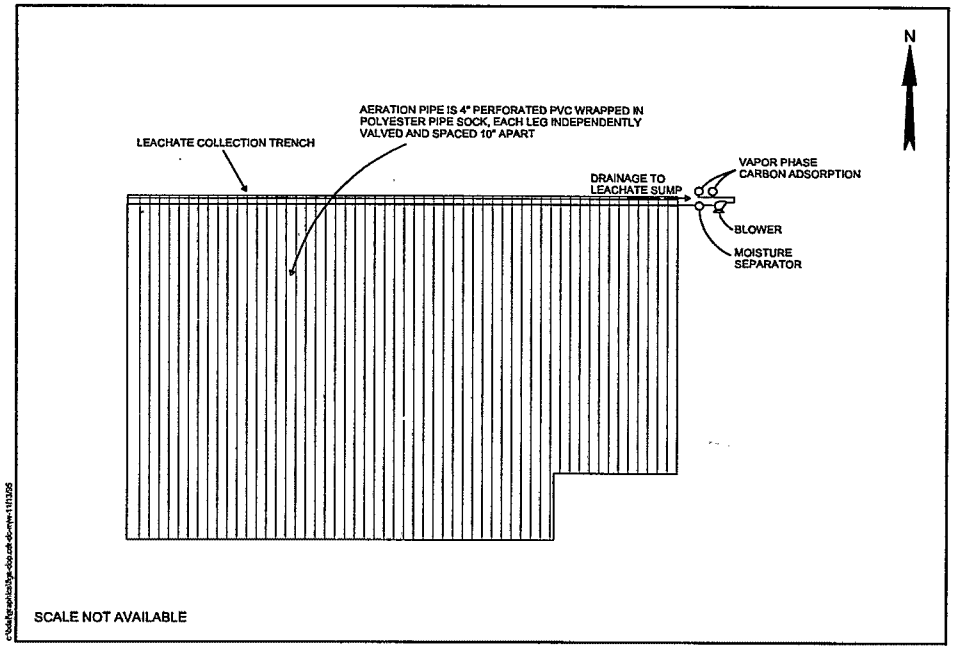

Figure 5. Layout of Aeration System Used at DOPC (top view) [17]

Figure 5. Layout of Aeration System Used at DOPC [17]

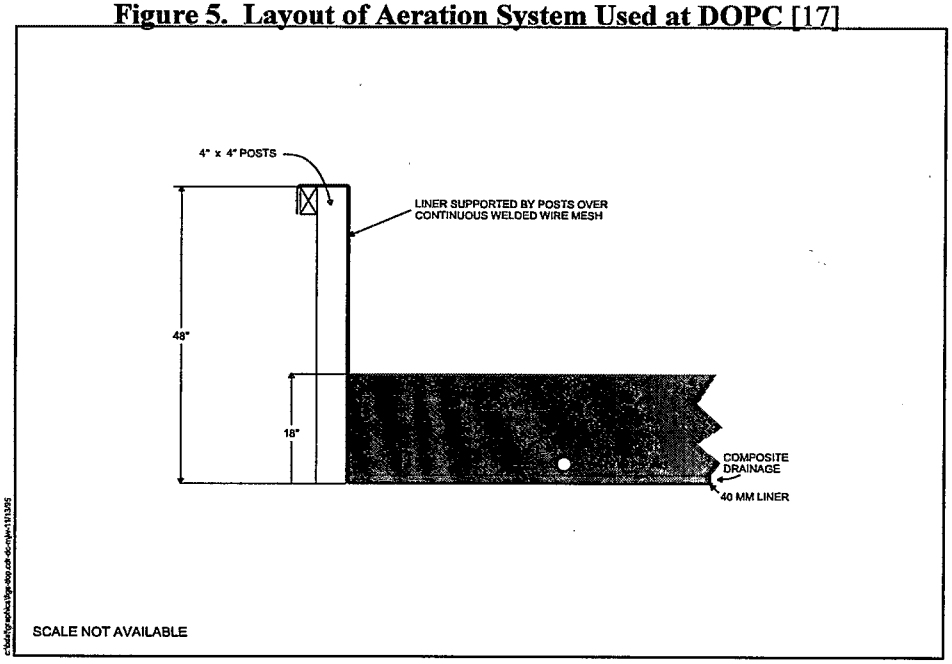

Figure 6. Location of Aeration Piping at DOPC [17]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Compost System Description and Operation (cont.)

The VOC-containing air discharged from the blower passed through two Carbtrol W-2 vapor phase carbon adsorbers plumbed in parallel. Each of these units contained 300 pounds of granular activated carbon (GAC) and were designed to treat a maximum air flow of 250 cfm. According to WATEC, a total of 1,800 pounds of GAC were used in this application. VOCs in the carbon exhaust were monitored daily, and carbon switchouts were made as appropriate to avoid VOC breakthrough. WATEC reported that they had given consideration to recirculating air from the carbon exhaust to the soil stockpile, but decided that the system was performing adequately without doing so and therefore they chose to not perform recirculation.

Inoculum Growth and Application System [17, 18]

The inoculum growth and application system consisted of two inoculum growth tanks, an inoculum mixing tank, and a pump and fire hose for dispensing the mixture. A schematic of this system is shown in Figure 7. Two 2,000-gallon polyethylene tanks were used to grow the inoculum, using indigenous site soil, water, nutrients, and air. Indigenous site soil was found to contain sufficient microbial activity to support the composting process. Inoculum was allowed to grow for at least 7 days before use in the treatment structure.

The inoculum mixing tank was a 5,000-gallon polyethylene tank equipped with a Lightnin Vector 1-1/2 horsepower high speed mixer operated at 750 rpm. A portion of the inoculum from the growth tank was mixed with additional nutrients and water in this tank. The inoculum mixture was pumped from the mixing tank using a Pulsafeeder centrifugal pump and a firehose and nozzle at 20 gallons per minute.

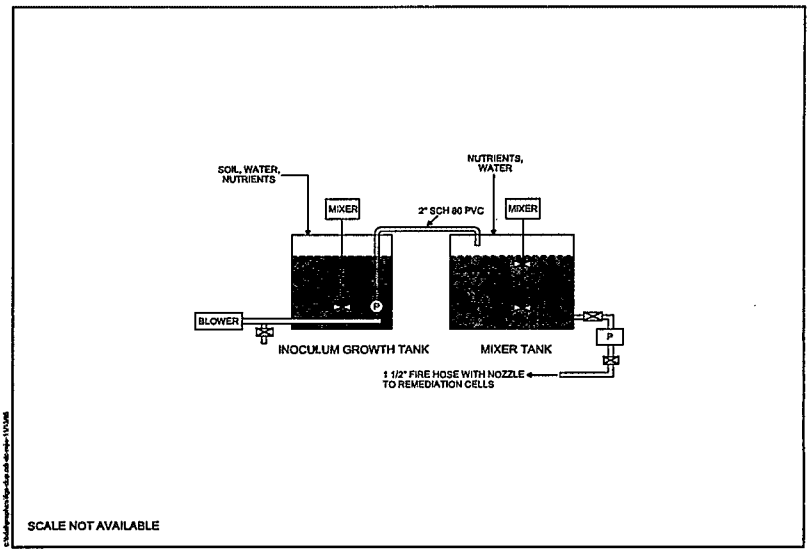

Figure 7. Inoculum Growth and Application System Schematic [17]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Compost System Description and Operation (cont.)

It was anticipated that a cometabolite (molasses) would need to be added to the mixture in this tank to support the microbial population, however, this proved unnecessary. The treatment vendor identified several possible reasons for this, including higher than expected soil TPH concentrations, and smaller than expected concentrations of high ring contaminants and PCP.

On-Site Wastewater Treatment System [31]

The on-site wastewater treatment system consisted of the following components:

- A 250,000-gallon influent storage tank;
- A 6,000-gallon iron oxidation reactor tank and clarifier;
- Two multimedia (gravel, garnet, sand, and anthracite) filters each rated at 50 gpm;
- Two granular activated carbon (GAC) filters rated at 200 gpm and operated at 50 gpm to provide an empty bed contact time of 25 minutes through each filter; and
- A 10,000-gallon effluent storage tank.

System Operation [31]

Each of the three bays in the treatment structure was used as a treatment cell, and soil was treated in each cell on a batch basis. A batch of soil contained between 660 and 2,310 tons of soil, depending upon the size of the bay and the depth of the soil being treated. For most of the batches, soil depth ranged from 4.0 to 4.25 feet.

Soil from the vault or other hot spots was transported to the treatment cells and spread in the cell. The soil in the cell was then marked into 165 cubic yard grids. Each grid was sampled and analyzed for VOCs, PCP, and PAHs. Grids that contained VOCs, PCP, or PAHs at concentrations greater than the soil cleanup goals (see discussion under cleanup goals and standards) were left in the treatment cell. Soil in grids that did not exceed any of the cleanup goals was removed from the cell and transported to the soil disposal area, as shown in Figure 3. Soil was moved in and out of the facility with a 2-1/2 or 4-1/2 yard rubber tire front end loader.

Of the 58,559 tons of soil excavated at the DOPC site, 19,705 tons were treated using the composting system. The other 38,854 tons of soil excavated met the soil cleanup standards and did not require treatment.

Aeration of the soil was accomplished using an aeration system sized to introduce a soil pore volume once every 90 minutes, and to maintain a pore space oxygen content of approximately 20 percent. Air flow rate was maintained at between 250 and 300 cfm for the application.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Compost System Description and Operation (cont.)

Inoculation of the soil was performed by adding the inoculum mixture to the soil relatively slowly, at about 20 gallons per minute and continued until the entire surface area of the cell was moistened. Generally, a batch was inoculated over a period of two days to provide time for the water to soak into the soil, while minimizing surface puddling or runoff. A soil moisture content of approximately 15% and a carbon:nitrogen:phosphorus ratio of 120:10:2 was maintained during this application.

Leachate collected from the soil was treated in the on-site wastewater treatment system to remove excess nutrients and other contaminants.

Early in the project, the treatment vendor was concerned that simply applying the inoculum mixture to the top of the soil mass with a fire hose may not allow for adequate diffusion of soil moisture to the bottom of the soil mass. To address this concern, they conducted a field pilot test of the soil moisture in a batch at various depths before and after application. The test showed that after 24 hours, soil moisture was relatively homogenous (plus or minus 2 percent) throughout the soil mass, and that there was adequate diffusion of moisture throughout the soil mass.

Disposition of Treated Soil [31]

According to the PRP steering committee oversight contractor, the composting system treated all soil batches to the cleanup levels within 14 to 30 days. In addition, the contractor stated that 88% of the soil was treated to meet the cleanup goals within 14 days; however, no data supporting this percentage are provided in the available references. As shown in Figure 8, contaminated soil was transported from the soil vault or other hot spot to the treatment structure. Treated soil was then transported to an on-site soil disposal area.

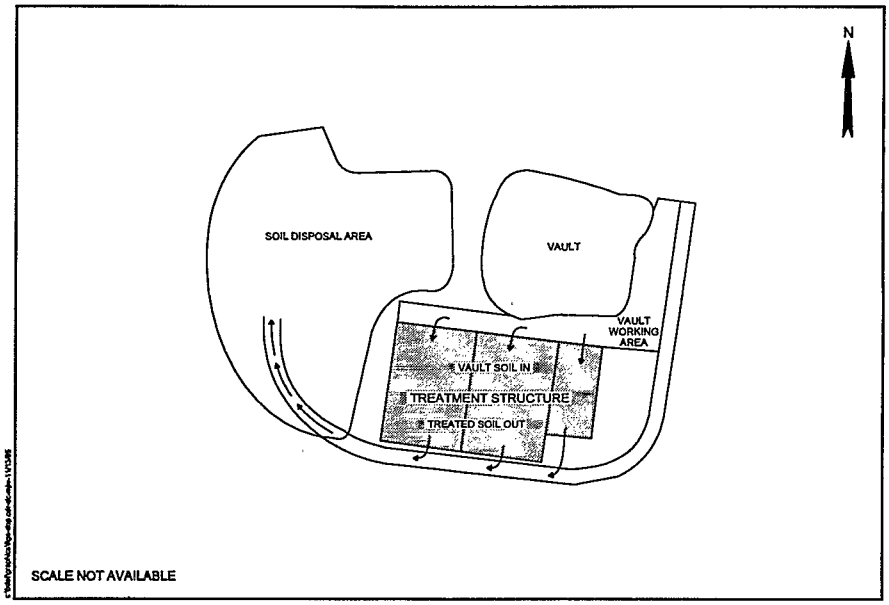

Figure 8. Schematic Showing Movement of Soil [18]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Compost System Description and Operation (cont.)

System Shutdown

After all soil piles were treated to meet the cleanup standards, the treated soil was sampled and excavated, piping and liner materials were removed, and the soil beneath the liner was sampled to verify that contaminants had not migrated beneath the liner. The excavation was then backfilled with treated soils (which had been stored in the ravine area at the site) to above grade, and a limited quantity of topsoil was placed on top of the excavation. The site was graded, erosion control measures were installed, and vegetation was applied. The ROD had required Dubose to apply two feet of topsoil over all the excavation, however, the actual quantity of topsoil applied was less than two feet. It is not known if this difference in topsoil quantity had any affect on vegetation growth. No information was provided in the available references on why the actual quantity used differed from the ROD specification.

Health and Safety [32]

All work at the site was performed using Level B personal protective equipment (e.g., supplied air respiration). The vendor monitored work zone and breathing zone ambient air contaminants throughout the remediation, and reportedly never identified any elevated concentrations that would have required them to implement their contingency plan.

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameters affecting cost or performance for this technology and the values measured for each are shown in Table 3.

Table 3. Operating Parameters [3, 17, 18, 31]

Parameter	Value	Measurement Method
Air Flow Rate	250 to 300 cfm	N/A
Mixing Rate/Frequency	No mixing in compost pile	N/A
Moisture Content	15%	N/A
pH	6.9 to 7.9	N/A
Residence Time	14 to 30 days/batch	N/A
Temperature	ambient	N/A
Oxygen Uptake Rate	not measured	-
Hydrocarbon Degradation	not measured	-
Nutrients and Other Soil Amendments	C:N:P:120:10:2	not available
Soil Loading Rate	660 to 2,310 tons/batch soil depth 4.0 to 4.25 feet	N/A
Soil Oxygen Content	approximately 20% (one soil volume every 90 minutes)	N/A

N/A - Measurement method not reported for this parameter because resulting value not expected to vary among measurement methods.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Timeline

A timeline for this application is shown in Table 4.

Table 4. Timeline [1, 31, 32]

Start Date	End Date	Activity
January 1979	November 1981	Waste storage, treatment, recycling, and disposal facility operated by DOPC
March 1982	May 1982	EPA and FDEP inspect and sample site
November 1984	May 1985	Contaminated soil excavated and placed in on-site vault
June 1986	-	DOPC listed on NPL
October 1987	-	Consent agreement reached by FDEP and DOPCSC
February 1988	October 1988	Remedial investigation performed
March 1990	-	ROD signed
May 1993	November 1993	Site preparation activities performed
November 1993	September 1994	Soil vault excavation and treatment activities performed
September 1994	August 1, 1996	Site restoration and remediation facilities demolition performed
August 19, 1996	-	Final site inspection performed.
September 1996	-	Final Remedial Action Report issued (approved February 1997)

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

The ROD identified soil cleanup goals and leachate discharge cleanup standards for total PAHs, PCP, total xylenes, benzene, TCE, and DCE, as shown in Table 5. [1]

Table 5. Cleanup Goals and Standards [1]

Constituent/Parameter	Soil Cleanup Goal (mg/kg)	Leachate Discharge Standard (µg/L)
Total Polynuclear Aromatic Hydrocarbons (PAHs)	50	10
Pentachlorophenol (PCP)	50	30
Total Xylenes	1.5	50
Benzene	10	1
Trichloroethene (TCE)	0.050	3
1,1-Dichloroethene (DCE)	0.070	7

Additional Information on Goals

Cleanup goals for constituents/parameters in the soil were based on either leaching potential or health-based criteria, as follows [1]:

- Leaching potential: Total PAHs, total xylenes, TCE, and DCE.
- Health-based criteria: PCP and benzene.

Treatment Performance Data

As discussed under treatment system description, soil placed in the treatment cells was divided into grids, then analyzed to determine if the grid contained levels of constituents of concern above the cleanup goals. Only soil in grids where the contaminants exceeded the cleanup goals was treated. Treatment performance data consist of soil samples for 286 grids of soil from the soil vault, 68 grids of soil from the west berm, and 5 grids of soil from the silo (359 grids total), and air emission samples at and near the perimeter of the site.

Soil Samples [31, 32]

A total of 359 grid samples were analyzed for benzene, DCE, TCE, total xylenes, PCP, and total PAHs. Of the 359 grids, 56 (16%) contained total PAHs at concentrations greater than the cleanup goal (50 mg/kg) and 102 contained VOCs, primarily xylenes, in excess of the VOC cleanup goals. The 56 grids exceeding the total PAH cleanup goal contained 8,783 tons of soil. Table 6 shows the grid number and contaminant concentrations before- and after-treatment for the 56 grids that exceeded the total PAH cleanup goal. The 102 grids exceeding the cleanup goal for VOCs contained 10,922 tons of soil. Thus, 19,705 tons of soil (8,783 tons for PAHs and 10,922 tons for VOCs) required treatment.

Table 6. Before- and After-Treatment Concentrations for 56 of 359 Grids [31]*

Grid No.		Before-Treatment Concentrations (mg/kg)						After-Treatment Concentrations (mg/kg)					
UVS	LVS	Total PAHs	PCP	Total Xylenes	Benzene	TCE	DCE	Total PAHs	PCP	Total Xylenes	Benzene	TCE	DCE
Cleanup Goal		50	50	1.5	10	0.05	0.07	50	50	1.5	10	0.05	0.07
118	013	59.02	7.67	21.6	0.05	0.03				0.40			
133	024	63.2		1.4				19.8		0.2			
137	036	67.7		1.4				15.1		0.04	0.03		
138	025	51.7		0.47				11.1					
148	026	54.3		0.19									
151	035	63.9		0.45				9.2		0.08			
163	029	55.6		6.36				11.1					
164	030	61.4		10.9				18.0	22.3	0.08			
165	031	53.3		4.0		0.02		24.5		0.13			
167	032	122.2		0.15				32.6	21.1	0.4		0.01	
168	037	73.2		0.41		0.02		22.2	18.6				
169	038	123.4	43.3	0.29		0.02		4.1		0.26			
171	034	58.0	26	58.6	0.3	1.0		13.1					
175	040	59.7		5.8				31.1	17.9	0.05			
188	042	57.0		0.07				21.5		0.04			
192	044	51.7		0.68				3.9		0.09			
198	048	53.0	17.9	11.1	0.02	0.05		35.1					
202	052	109.2		17.4	0.08	0.47		17.5		0.13			
219	066	52.5		4.00	0.01			3.3					
221	067	59.7		5.31	0.02			27.6		1.05			
224	068	84.3	31.1	5.43	0.04	0.07		15.6		0.36		0.04	
226	069	53.6		11.9	0.09	0.14		5.6		0.53			
233	072	106.3		0.97				3.3		0.09			
235	074	96.0		48.9				28.5		0.65			
236	075	60.8		5.70									
237	076	132.1	29.7	15.5				15.6		0.11			
238	077	222.6		69.5	0.50			49.9		0.65			
239	078	78.0		0.18				30.2		0.04			
240	079	232.50	92.7	22.5									
241	080	73.6		17.1				15.5		0.03			
242	081	111.1		23.5				18.0					
243	082	62.0		24.5				12.6		0.14			
244	083	246.2	104.6	13.9				15.7					
WB14	102	105.7								0.10			

Table 6 (Continued)

Grid No.		Before-Treatment Concentrations (mg/kg)						After-Treatment Concentrations (mg/kg)					
UVS	LVS	Total PAHs	PCP	Total Xylenes	Benzene	TCE	DCE	Total PAHs	PCP	Total Xylenes	Benzene	TCE	DCE
Cleanup Goal		50	50	1.5	10	0.05	0.07	50	50	1.5	10	0.05	0.07
WB16	103	55.1		0.30						0.16			
251	086	175.3		4.12	0.02			3.8					
255	089	60.1		0.420				4.5		0.13			
256	090	78.7	20.1	2.50		0.25		26.9		0.57			
258	091	61.2		22.5				36.3	16.5	0.05			
259	092	576.2		16.6				23.1		0.95			
260	093	66		10.9				49.9	36.3				
261	094	119.2	27.0	28.5				25.4		0.56			
263	096	66.5		9.0				21.9		0.76			
266	099	117.2		0.44									
267	100	68.0		0.64				15.5					
268	101	297.7		44		0.80		13.4		0.455			
273	106	50.8		1.05		0.01		18.6		0.49			
274	107	51.9	17.3	8.0				44.5		0.56			
275	108	139.1	97.4	24.2									
281	111	186.8	100	29.4									
282	112	101.3	44.6	16.8									
286	116	76.4	16.8	21.1									
WB29	118	69.9		0.33									
WB40	120	166.6		0.49				4.2					
WB41	121	200.3											
WB43	122	191.6	160	2.03									

*This table shows analytical results only for the 56 of 359 grids that contained total PAHs at concentrations exceeding the cleanup goal (50 mg/kg). UVS means upper vault samples and LVS means lower vault samples. Where no data are shown (blanks in table), analytical result was below detection limit.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

The treatment vendor calculated the average concentrations for 17 PAHs measured in grids 101 through 221 before-treatment and after 14 days of treatment. The average concentrations for these constituents in grids that required treatment are shown in Table 7. In addition, for grids 101 through 221, which consisted of approximately 20,000 cubic yards of soil, the treatment vendor estimated that 9,900 cubic yards (50%) required treatment, including 2,970 cubic yards (15%) for total PAHs and 6,930 cubic yards (35%) for VOCs.

The treatment vendor indicated that, while the primary removal mechanism for PAHs was bioremediation, the primary removal mechanism for VOCs was volatilization, either in handling or through the aeration system. Before- and after-treatment data for the 102 grids exceeding the cleanup goal for VOCs are not presented in this report because the vendor believes these constituents were removed through volatilization rather than bioremediation.

According to the RPM, the soil was handled at least twice before undergoing composting, and there may have been some limited amount of fugitive losses during such handling. However, no data were collected to evaluate potential fugitive losses. In addition, work zone and breathing zone ambient air monitoring data for VOCs was collected throughout the remediation. These data never triggered the requirement to implement a contingency plan which would have had to be implemented if elevated concentrations were identified. The only contaminants measured in the ambient monitoring system were phenanthrene and naphthalene, and these contaminants were measured at concentrations less than their contingency levels. During aeration, all VOCs extracted from the soil were treated using the GAC system prior to release to the atmosphere.

Air Emission Samples [31]

Air emission samples were collected at four air monitoring stations, each consisting of a volatile organic sampler (Xontech sampler) and a semi-volatile sampler (PS-1). Air monitoring was planned as a contingency measure in the event of a release or suspected release of airborne contaminants, and for monthly documentation during soil excavation/ transport activities.

No contingency monitoring was required by events occurring during the project. Monthly monitoring was performed over nine 24-hour periods when contaminated soil excavation/transport activities were underway.

According to the DOPCSC oversight contractor, analytical results of the air emission samples indicated all contaminants of concern were present at levels below levels of concern. These data are not provided in the available references, but are available in the detailed files for the project. [34]

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Table 7. Soil Treatment Results for Individual PAHs [18][1]

Constituent	Average Concentration in Soil Before Treatment (mg/kg)	Average Concentration in Soil After 14 Days of Treatment (mg/kg)
Two-Ring PAHs		
Naphthalene	1.48	BDL
2-Methyl Naphthalene	1.11	0.26
Acenaphthylene	BDL	BDL
Acenaphthene	4.15	0.74
Three-Ring PAHs		
Fluorene	5.2	0.89
Phenanthrene	16.5	3.6
Anthracene	26.4	7.94
Four- and Five-Ring PAHs		
Fluoranthene	9.56	5.28
Pyrene	5.52	4.35
Benzo(a)anthracene	BDL	BDL
Chrysene	BDL	BDL
Benzo(b)fluoranthene	BDL	BDL
Benzo(k)fluoranthene	BDL	BDL
Benzo(a)pyrene	BDL	BDL
Indeno(1,2,3-cd)pyrene	BDL	BDL
Dibenz(a,h)anthracene	BDL	BDL
Benzo(g,h,i)perylene	BDL	BDL

[1]This table shows average concentrations for only those grids within grid numbers 101 through 221 that required treatment for PAHs.
BDL - Below Detection Limit.

Performance Data Assessment

As discussed under treatment performance data, 56 of the 359 soil grids excavated at the DOPC site (corresponding to 8,763 of 58,559 tons of soil) required treatment for total PAHs. The analytical data for these soil grids summarized in Table 6 show that before-treatment concentrations of total PAHs ranged from 50.8 mg/kg to 576.2 mg/kg, with 21 of the 56 grids containing total PAHs at concentrations more than twice the soil cleanup goal for total PAHs (50 mg/kg). The after-treatment concentration data shown in Table 6 indicate that all 56 grids met the soil cleanup goals for total PAHs, PCP, total xylenes, benzene, TCE, and DCE. Total PAHs in the 56 treated soil grids ranged from 3.3 mg/kg to 49.9 mg/kg, and the average concentration of total PAHs in the treated soil was 19 mg/kg.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (cont.)

In addition, for these 56 soil grid samples, PCP before-treatment concentrations ranged from 7.67 mg/kg to 160 mg/kg, and after-treatment concentrations ranged from 16.5 mg/kg to 36.3 mg/kg; total xylenes before-treatment concentrations ranged from 0.07 mg/kg to 69.5 mg/kg, and after treatment concentrations from 0.03 mg/kg to 1.05 mg/kg; and TCE before-treatment concentrations ranged from 0.01 mg/kg to 1.0 mg/kg, and after treatment concentrations from 0.01 mg/kg to 0.04 mg/kg. Benzene and DCE were not measured at concentrations greater than their soil cleanup goals in these 56 grids.

Analytical data for individual PAHs shown in Table 7 indicate that the majority of PAHs measured at detectable concentrations in the soil in grid numbers 101 through 221 before treatment were two- and three-ring constituents. Six of the seven two- and three-ring PAHs shown in Table 7 had detectable concentrations before treatment, averaging up to 26.4 mg/kg for anthracene (a three-ring PAH), while only two of the ten four- and five-ring PAHs had detectable concentrations. Also as shown in Table 7, two- and three-ring PAHs showed approximately 80% reduction in average concentration after 14 days of treatment for these grids, while four- and five-ring PAHs showed less than 50% reduction in average concentration over the same time period.

Before- and after-treatment data for the 102 grids exceeding the cleanup goal for VOCs are not presented in this report because the vendor believes these constituents were removed through volatilization rather than bioremediation.

Performance Data Completeness

Treatment performance data are available to characterize the before- and after-treatment concentrations for total PAHs, PCP, total xylenes, benzene, TCE, and DCE in the soil excavated at the DOPC site; and the range of operating parameters monitored in this application. In addition, the PRP steering committee oversight contractor reported that air emission monthly monitoring samples are available for nine 24-hour periods during excavation/transport activities. No data are available to link specific operating parameters with treatment performance data for individual batches (e.g., residence time, application of inoculum).

Performance Data Quality

The treatment vendor performed extensive quality assurance/quality control (QA/QC) procedures as part of this remedial activity. QA/QC procedures included development of a Quality Assurance Project Plan (QAPP - Ref. 12), use of standard EPA analytical procedures, such as SW-846 Method 8270 for PAHs and PCP and 8010/8020 for VOCs, and use of trip blanks, field duplicates, matrix spikes, and matrix spike duplicates. No exceptions to the QA/QC procedures were noted by the vendor for this treatment application. [31]

TREATMENT SYSTEM COST

Procurement Process

The PRP Steering Committee selected WATEC as the remedial action treatment vendor and Parsons Engineering Science, Inc. as the oversight contractor. WATEC designed, constructed, and operated the composting process at the DOPC site, and Parsons performed oversight activities, including sample collection and analysis, and preparation of a remedial action report.

No information is provided in the available references on the competitive nature of the two procurements; how many bids were provided for each function; or what was the basis for contractor selection.

Treatment System Cost

Actual costs of $7,736,700 were reported by the PRP steering committee's oversight contractor for this application, as shown in Table 8. Table 8 shows the specific activity and corresponding cost as reported by the oversight contractor.

Table 8. Costs Reported by PRP Steering Committee [31]

Activity	Actual Cost ($)
Oversight by PRP Group	17,500
Remedial design	820,000
RI/FS	940,000
North pond effluent	18,500
Vault and north pond dike	5,000
Air monitoring	57,200
Groundwater and surface water monitoring	450,000
Site security fencing	9,300
Vault cover replacement	35,500
Repair of north pond dike	18,600
Miscellaneous (accounting, hog barn demolition, entrance road construction, tire disposal)	46,600
O&M of leachate treatment	42,500
Drums/Tanks/Structures/Miscellaneous Demolition and Removal	26,000
Remedial action/construction	4,780,000
DOPCSC remedial action oversight	470,000
TOTAL	7,736,700

TREATMENT SYSTEM COST (CONT.)

Cost Data Quality

The costs for specific activities shown in Table 8 represent actual costs for those activities as reported by the PRP steering committee oversight contractor. No information was contained in the available references on the components of these specific activities, or the costs for those components (e.g., for the $4.78 million expended on remedial action/construction).

Vendor Input

WATEC reported that a performance-based specification would be better suited for these types of projects. They reported that the design package on which they bid was not subsequently implemented, and that such changes would be accommodated more easily with a performance-based specification. [32]

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- Actual costs of $7,736,700 were reported by the PRP Steering Committee's oversight contractor for this application including $4,780,000 for remedial action/construction activities.

- Costs included the following WBS cost elements: mobilization and preparatory work, monitoring, sampling, testing, and analysis, site work, surface water collection and control, drums/tanks/structures/miscellaneous demolition and removal, and operation (short-term, up to 3 years).

- Based on the cost information provided by the PRP, costs for activities directly attributed to treatment could not be separated from before- and after-treatment costs, and therefore unit costs for activities directly attributed to treatment were not calculated or available for this application. The cost of $4,780,000 provided by the PRP includes costs for excavation, storage, sampling, and analysis, which are considered before-treatment cost elements, costs for disposal, which is considered an after-treatment cost element, as well as costs directly attributed to treatment. No information was provided to disaggregate the remedial action/construction cost into discernible costs and activities.

- The RPM for this application expressed a preference for contracts which allow for flexibility in remedial design, stating that the use of a flexible design including temporary treatment structures in this application resulted in significant cost savings.

Performance Observations and Lessons Learned

- Soil cleanup goals for all 19,705 tons of soil treated at the DOPC site were met in this application. Of the 58,559 tons excavated, 19,705 tons required treatment because one or more constituents were measured at concentrations greater than the cleanup goals, including 8,783 tons containing total PAHs at concentrations greater than the cleanup goals, and 10,922 tons containing VOCs (primarily xylenes).

- The analytical data for the 8,763 tons of soil that required treatment for total PAHs (corresponding to 56 sampling grids) indicate that before-treatment concentrations of total PAHs ranged from 50.8 mg/kg to 576.2 mg/kg, with 21 of the 56 grids containing total PAHs at concentrations more than twice the soil cleanup goal for total PAHs (50 mg/kg). Total PAHs in the 56 grids after treatment ranged from 3.3 mg/kg to 49.9 mg/kg, and the average concentration of total PAHs in the treated soil was 19 mg/kg.

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Performance Observations and Lessons Learned (cont.)

- For these 56 soil grid samples, PCP before-treatment concentrations ranged from 7.67 mg/kg to 160 mg/kg, and after-treatment concentrations ranged from 16.5 mg/kg to 36.3 mg/kg; total xylenes before-treatment concentrations ranged from 0.07 mg/kg to 69.5 mg/kg, and after treatment concentrations from 0.03 mg/kg to 1.05 mg/kg; and TCE before-treatment concentrations ranged from 0.01 mg/kg to 1.0 mg/kg, and after treatment concentrations from 0.01 mg/kg to 0.04 mg/kg. Benzene and DCE were not measured at concentrations greater than their soil cleanup goals in these 56 grids.

- Analytical data for individual PAHs indicate that the majority of PAHs measured at detectable concentrations in approximately one-third of the grid samples before treatment were two- and three-ring constituents. Six of the seven two- and three-ring PAHs had detectable concentrations before treatment, averaging up to 26.4 mg/kg for anthracene (a three-ring PAH), while only two of the ten four- and five-ring PAHs had detectable concentrations.

- Analytical data indicated that two- and three-ring PAHs showed approximately 80% reduction in average concentration after 14 days of treatment, while four- and five-ring PAHs showed less than 50% reduction in average concentration over the same time period.

Other Observations and Lessons Learned

- The primary removal mechanism for VOCs was volatilization, either in handling or through the induced draft aeration system, and the primary removal mechanism for PAHs was bioremediation. In addition, according to the treatment vendor, no VOCs or PAHs were detected in the leachate at the influent to the wastewater treatment facility, indicating that contaminants were not "washed" from the soil in this application.

- According to the RPM, the soil was handled at least twice before undergoing composting, and there may have been some limited amount of fugitive losses during such handling. However, no data were collected to evaluate potential fugitive losses, and work zone and breathing zone ambient air monitoring data for VOCs collected throughout the remediation never triggered Dubose to implement their contingency plan. The only contaminants identified in the ambient monitoring system were phenanthrene and naphthalene, and these contaminants were measured at concentrations less than their contingency levels.

- The composting system treated soil to the cleanup levels within 14 to 30 days on a batch basis. The overall process of excavating and treating soil at the DOPC site was completed within a 10 month period.

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Other Observations and Lessons Learned (cont.)

- A co-metabolite was not required to be used for inoculum growth in this application, contrary to the original plan. The treatment vendor identified several possible reasons for this, including higher than expected soil TPH concentrations, and smaller than expected concentrations of high-ring contaminants and PCP.

- The treatment vendor found that applying the inoculum mixture to the top of the soil mass with a fire hose was adequate for maintaining the moisture content of the soil mass. A field pilot test showed that soil moisture was relatively homogeneous throughout the soil mass (plus or minus 2 percent) within 24 hours after inoculum application.

- The treatment vendor identified several items that required unexpected maintenance during system operation, including the moisture separator and the aeration piping. The quantity of rain experienced during this application exceeded original predictions, and the moisture separator capacity was frequently exceeded. The vendor modified the operation of the moisture separator during the application by installing a control panel and automatic drain so the unit would drain and re-start automatically. Also, some of the aeration piping occasionally was crushed, because of the relatively thin layer of sand protecting the piping and the use of heavy equipment in the treatment structure.

- The RPM noted a problem with planting grass as the final cover over this site, saying that the treated soil was not supporting the growth of Bahia grass, and that there was a need to place topsoil over the treated soil before planting grass.

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4. Plans and Specifications for the Remedial Action Final (100 Percent), Volume III - Air Monitoring Plan, for the Dubose Oil Products Company Site. Engineering-Science. February 1993.

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5. Plans and Specifications for the Remedial Action Final (100 Percent), Volume IV - State and Local Permit Plan, for the Dubose Oil Products Company Site. Engineering-Science. January 1993.

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14. Plan for Demobilization of Existing Wastewater Treatment Plant, Dubose Oil Products Company Site, Cantonment, Florida, for DOPC Steering Committee and Engineering-Science, Inc. Waste Abatement Technology, L.P. October 1993.

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30. Meeting Notes. Meeting on 9/25/95 between Tim McLaughlin, Radian Corporation, and Mark Fite, RPM.

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32. Comments provided by Mark Fite, RPM (by telephone), to Richard Weisman, Radian, February 27, 1997.

33. Material concerning Treatability Study, provided by Mark Fite, RPM, March 4, 1997.

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Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Radian International under EPA Contract No. 68-W3-0001 and U.S. Army Corps of Engineers Contract No. DACA45-96-D-0016.

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

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

Case Study Abstract

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).

COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for a slurry phase bioremediation application at the Southeastern Wood Preserving Superfund site, in Canton, Mississippi. Slurry phase bioremediation was used at the Southeastern Wood site to treat soil and sludge contaminated with polynuclear aromatic hydrocarbons (PAHs), including acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(b and k)fluoranthenes, benzo(ghi)perylene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene.

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.

The application at Southeastern Wood was completed as a removal action, under an action memorandum signed in September 1990. A slurry phase bioremediation system was operated 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. Cleanup goals for this application were developed based on the results of laboratory and field pilot tests and a site-specific health-based risk analysis, and consisted of the following: total PAHs - 950 mg/kg, and B(a)P-equivalent PAHs - 180 mg/kg. These goals were provided in an LDR treatability variance for this application.

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. The analytical data indicate that the majority of biodegradation occurred during the first 5 to 10 days of treatment, and the cleanup goal for total PAHs was met for 12 of the 13 batches within approximately 19 days of treatment.

Approximately $2,900,000 were expended in this application, consisting of $2,400,000 for activities directly attributed to treatment (mobilization/setup, startup/testing/permits, and operation), and $500,000 for after-treatment activities (site restoration). The cost for activities directly attributed to treatment corresponds to $170 per ton ($230 per cubic yard) of soil and sludge treated (14,140 tons, or 10,500 cubic yards).

SITE INFORMATION

Identifying Information:

Southeastern Wood Preserving Superfund Site
Canton, Mississippi
CERCLIS # MSD0008258558
Action Memorandum Date: 9/30/90

Treatment Application:

Type of Action: Removal
Treatability Study Associated with Application? Yes
(see additional information under Background and Operation below)
EPA SITE Program Test Associated with Application? No

Period of Operation: 1991-1994

Quantity of Material Treated During Application: 14,140 tons (10,500 cubic yards) of soil and sludge

Background

Historical Activity that Contributed to Contamination at the Site: Creosote wood preserving
Corresponding SIC Code: 2491B (Wood Preserving Using Creosote)
Waste Management Practice that Contributed to Contamination: Manufacturing Process, Surface Impoundment/Lagoon

Site History:
The Southeastern Wood Preserving Superfund Site is an abandoned wood preserving facility located in Canton, Mississippi, as shown in Figure 1. The facility was used for creosote wood preserving activities between 1928 and 1979. In 1986, EPA initiated an emergency response action at the site to stabilize three unlined surface impoundments which were overflowing.

The impoundments were dewatered and bottom sediment sludge was excavated and stabilized using approximately 70 cubic yards of cement kiln dust.

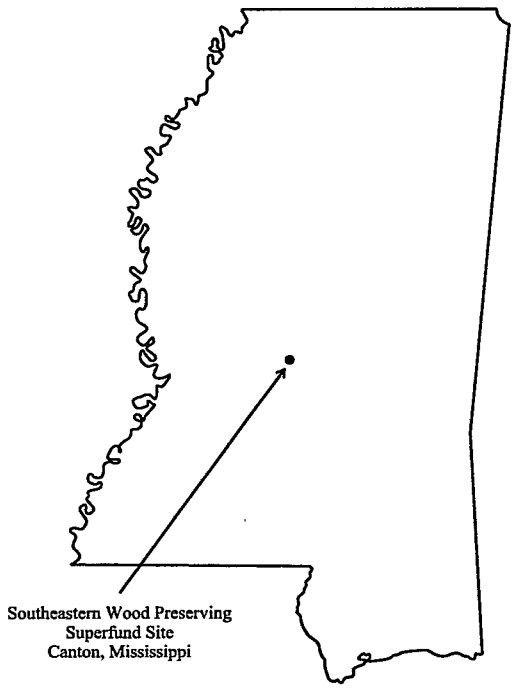

Figure 1. Site Location [1]

SITE INFORMATION (CONT.)

Background (cont.)

Excavation was based on a visual assessment of contamination. EPA sampled this material in April 1989, and found it to be contaminated with polynuclear aromatic hydrocarbons (PAHs), at levels of approximately 4,000 mg/kg, as shown in Table 1. The contaminated material from the lagoon was classified as a RCRA K001-listed hazardous waste (bottom sediment sludge from the treatment of wastewaters from wood preserving processes which used creosote). The excavated material was stockpiled on site for further treatment. [1, 2, 12]

Regulatory Context: This application was conducted as part of a removal action at the site. Cleanup goals were developed based on the results of bench-scale and field pilot studies using bioremediation and a site-specific health-based risk analysis.

Remedy Selection: Slurry-phase bioremediation was selected for this application on the basis of cost. In addition, slurry-phase bioremediation was identified as preferable to land treatment because it was believed to treat the soil in a shorter period of time and to achieve lower concentrations in the residual soil. [4, 9]

Table 1. Concentrations of PAHs in Excavated Material* [12]

Constituent	Concentration (mg/kg)
Acenaphthene	705
Acenaphthylene	78.8
Anthracene	2.44
Benzo(a)anthracene	496
Benzo(b)fluoranthene/ Benzo(k)fluoranthene	513
Benzo(ghi)perylene	9.8
Benzo(a)pyrene	224
Chrysene	305
Dibenzo(ah)anthracene	27.05
Fluoranthene	419
Fluorene	32.2
Indeno(1,2,3-cd)pyrene	64.1
Naphthalene	673
Phenanthrene	266
Pyrene	ND (0.36)
Total PAHs	3,815

ND - Not detected. Value in parentheses is the reported detection limit.
*Sample collected April 4, 1989.

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Management: Fund-Lead

Oversight: EPA

On-Scene Coordinator:

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

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

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: soil (ex situ) and sludge (ex situ)

Contaminant Characterization

Primary Contaminant Groups: Polynuclear Aromatic Hydrocarbons (PAHs)

The excavated material at the site contained PAH concentrations of approximately 4,000 mg/kg dry weight for total PAHs and from 1,000 to 2,500 mg/kg dry weight carcinogenic PAHs. Total PAHs are defined as the sum of the 16 constituents listed below. Carcinogenic PAHs are defined as the total concentration of the seven PAHs marked with an asterisk: [3]

- Acenaphthene;
- Acenaphthylene;
- Anthracene;
- Benzo(a)anthracene*;
- Benzo(b)fluoranthene*/ Benzo(k)fluoranthene*;
- Benzo(ghi)perylene;
- Benzo(a)pyrene*;
- Chrysene*;
- Dibenzo(a,h)anthracene*;
- Fluoranthene;
- Fluorene;
- Indeno(1,2,3-cd)pyrene*;
- Naphthalene;
- Phenanthrene; and
- Pyrene.

Matrix Characteristics Affecting Treatment Cost or Performance

The major matrix characteristics affecting cost or performance for this technology and the values measured for each are shown in Table 2.

Table 2. Matrix Characteristics [2, 9, 12]

Parameter	Value	Measurement Method
Soil Classification	Information not provided	Information not provided
Clay Content and/or Particle Size Distribution*	>10 mesh (gravel) 5% <10->200 mesh (sand) 40% <200 mesh (clay) 55%	Information not provided
Bulk density (of stockpiled material)	1.83 gm/cm^3	ASTM-D1298
Ash	66.8%	ASTM-D482
Sulfur	0.08%	ASTM-D129
Free liquids	None	SW-846-9095
Total Solids	71.5%	SM-209F

*Information was not provided in the available references on whether this distribution was for soil excavated from the site and/or treated in the bioreactors.

Various types of debris were present in the contaminated soil and sludge excavated at the site. The debris included large stones, plastic sheeting, concrete, and railroad ties. [2]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology Type: Slurry phase bioremediation

Supplemental Treatment Technology Type:
Pretreatment (Solids): screening, mixing
Post-Treatment (Solids): dewatering

Slurry Phase Bioremediation System Description and Operation

The slurry phase bioremediation system used at Southeastern Wood Preserving included a power screen, a slurry mix tank, four slurry phase bioremediation reactors (bioreactors), and a slurry dewatering unit. This system, shown in Figure 2, was used to separate out the larger particles (greater than 200 mesh, or 0.0029 inches) from the stockpiled soil and sludge, and to biologically treat the remaining soil and sludge particles (less than 200 mesh).

As shown on Figure 2, soil and sludge from the stockpile were power-screened to remove debris greater than 0.5 inches such as large stones, plastic sheeting, and railroad ties. The power-screening step removed approximately 450 cubic yards of material.

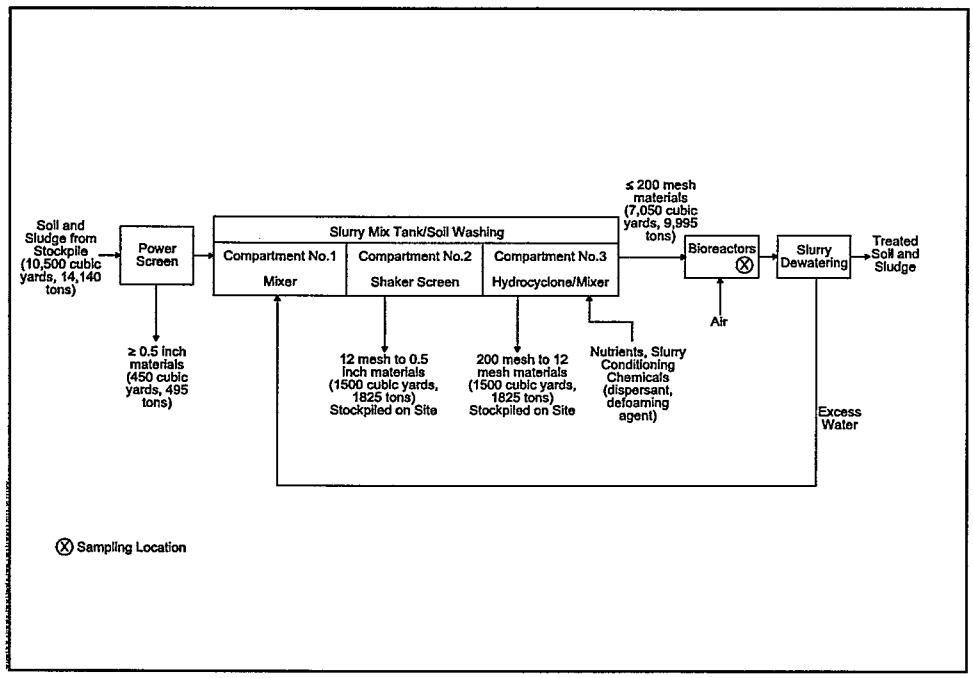

Figure 2. Slurry Phase Bioremediation System Used at Southeastern Wood Preserving [6]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Slurry Phase Bioremediation System Description and Operation (Cont.)

Soil and sludge that passed the power screening step were loaded into a slurry mix tank for soil washing. The mix tank contained three compartments:

- Compartment No. 1 - Water was added to slurry the solids.
- Compartment No. 2 - The slurry was pumped to a shaker screen to remove debris between 12 mesh (0.0661 inches) and 0.5 inches. Approximately 1,500 cubic yards of debris were removed by the shaker screen.
- Compartment No. 3 - A hydrocyclone removed approximately 1,500 cubic yards of materials (sand) and other materials between 200 mesh and 12 mesh.

In addition, nutrients and slurry conditioning chemicals (including a dispersant and defoaming agent) were added and mixed with the slurry in this compartment.

Materials removed by the shaker screen and hydrocyclone were stockpiled on site.

The slurry mixing/soil washing process was performed on a batch basis, with 20-30 minutes of processing time per batch.

Bioreactors [1, 2, 16, 26]
Four closed-top bioreactors were used in this application. Each bioreactor was 38 feet in diameter and 24 feet in height, and was equipped with diffusers and a blower for aeration and an impeller for mixing and keeping the slurry in suspension. Each bioreactor had an operating capacity of 180,000 gallons. The system was operated on a batch process, with each batch consisting of 160 to 180 cubic yards of material. Sixty-one batches were treated in this application, consisting of 17 batches in reactor 1, 23 batches in reactor 2, 14 batches in reactor 3, and 7 batches in reactor 4. During treatment, the slurry in the reactors was monitored daily for pH, temperature, dissolved oxygen, and other biological monitoring parameters, such as nutrient and biomass concentrations. Operating parameters and values for this application are shown in Table 3.

Excess water generated in the bioreactors was occasionally removed from the reactors. This excess water was first sampled, and, as appropriate, discharged to a POTW.

Operation [2, 9, 10]
Construction of the treatment facilities began in January 1991 and was completed in mid-April 1991. Demonstration testing began at that time and consisted of batch treatment of 700 cubic yards of soil. By late June 1991, the treatment vendor had demonstrated that the soil could be

TREATMENT SYSTEM DESCRIPTION (CONT.)

Slurry Phase Bioremediation System Description and Operation (Cont.)

treated in the reactors to the cleanup standards set in the contract. During the demonstration tests, the vendor also evaluated the performance of a land treatment unit (LTU) for this application. However, soil applied directly to the LTU did not meet the cleanup standards within this timeframe. In order to complete the demonstration test and receive EPA authorization to proceed with the project, the vendor decided to forego applying soil directly to the LTU and treated all soil in the reactors.

Operation of the full-scale soil treatment system began in July 1991. During full-scale operation, the vendor refined the operation by adding a slurry mix tank/soil washing (desanding) operation. The vendor found that keeping sand-sized particles in suspension in the reactors was extremely difficult, and they removed the sand prior to pumping the slurry to the reactors. The sand was analyzed separately and subject to the same clean up criteria as the fine grained particles.

Soon after full-scale operation began, the vendor began to have problems meeting the clean up standards within the anticipated 30 to 35 day reactor residence time. Specifically, problems were encountered with two compounds, pyrene and phenanthrene, which both have a K001 treatment standard of 1.5 mg/kg. The vendor identified non-homogeneity in the contaminated soil stockpile as the cause. During this early period of system operation, reactor residence time was running in the 60 to 80 day range. This problem was resolved by modifying the cleanup standards to be based on total PAH concentrations (i.e., the sum of 16 specific PAHs). This was accomplished by removing the K001 treatment standards - see additional discussion under Cleanup Goals.

Progress of the bioremediation process was measured using oxygen uptake rate (OUR). When the OUR showed a significant decline, the vendor would collect samples for chemical analysis.

The vendor noted that there was a problem with foam production during bioreactor operation. Foam would overflow the bioreactors, and the vendor had trouble containing the overflow. To correct this problem, the combination of dispersant and defoamer was revised, including addition of a lignin.

The bioreactors were located outdoors, and operated year round, but were not heated. The vendor specified that during the colder winter months, much slower degradation was observed. The bioreactor temperature ranged from 15°C to 21°C during the winter months. During the spring, summer, and fall, bioreactor temperatures ranged from 25°C to 40°C.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Slurry Phase Bioremediation System Description and Operation (Cont.)

Air Dispersion Modelling [11]
To assess emissions of volatile organic compounds (VOCs) and PAHs from the bioremediation process, the treatment vendor performed air dispersion modelling. The vendor modelled off-property ground-level VOC and PAH concentrations using the EPA Industrial Source Complex (ISC) dispersion simulation model. The results of the modelling showed that proposed activities would not result in any exceedence of accepted long-term exposure screening levels for this application.

Slurry Dewatering [9]
After treatment in the bioreactors, the slurry was transferred to a slurry dewatering unit, which was a 425-foot long, 160-foot wide, and 6-foot deep high density polyethylene (HDPE)-lined cell. The water recovery system, consisting of drain tiles in coarse sand, was sloped to a sump to collect excess water. Excess water was pumped to a 350,000-gallon water management tank and was reused for slurry preparation. Soil remaining in the slurry dewatering unit was tilled to further dry the treated material.

Treated soil and sludge were placed in a lined, capped disposal cell on site. Debris and sand were also placed in the cell.

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameters affecting cost or performance for this technology and the values measured for each are shown in Table 3.

Table 3. Bioreactor Operating Parameters [1, 2, 16]

Parameter	Value	Measurement Method
Air Flow Rate (SCFM)	350 ± 100	N/A
pH	7.2 ± 1.0	N/A
Residence Time (days)	8 to 29	N/A
System Throughput (yd^3 per batch)	160 to 180	N/A
No. of Batches Treated	61	N/A
Temperature (°C)	15 - 40	N/A
Biomass Concentration (cfu/ml)	10^7 - 10^8	Information not provided
Hydrocarbon Degradation	Not measured	---
Operating Volume (gallons)	180,000	N/A
Impeller Speed (RPM)	900	N/A
Solids Loading %	20	N/A
Initial Defoamer (mg/L)	200	N/A
Initial Dispersant (mg/L)	1,000	N/A
Dissolved Oxygen (mg/L)	>2.0	N/A

TREATMENT SYSTEM DESCRIPTION (CONT.)

Operating Parameters Affecting Treatment Cost or Performance (cont.)

Table 3. (Continued)

Parameter	Value	Measurement Method
NH_4-N (mg/L)	60 ± 20	Information not provided
PO_4-P (mg/L)	10	Information not provided

N/A - Measurement method not reported for this parameter because resulting value not expected to vary among measurement methods.

Timeline

A timeline for this application is shown in Table 4.

Table 4. Timeline [1, 2]

Start Date	End Date	Activity
1928	1979	Southeastern Wood Preserving operated as creosote wood treatment facility
April 1989	---	Initial samples collected from excavated materials
September 1990	---	Action memorandum signed
January 1991	April 1991	Treatment facility construction
April 1991	June 1991	Demonstration tests performed
July 1991	1994	Slurry phase bioremediation of soil and sludge performed

No additional details on the timeline for this application (e.g., for bioremediation activities) are provided in the available references.

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

The results of laboratory and field pilot tests and a site-specific health-based risk analysis were used to develop the following cleanup goals for this application:

- 950 mg/kg dry weight soil solids total PAHs; and
- 180 mg/ky dry weight soil solids of benzo(a)pyrene (B(a)P) - equivalent carcinogenic PAHs.

Total PAHs were defined in this application as the sum of the concentrations for the 16 constituents shown in Table 7. EPA used published toxicity-equivalent factors to calculate the B(a)P-equivalent of the carcinogenic PAHs (the carcinogenic PAHs are identified in Table 7). In calculating B(a)P-equivalent concentrations, the concentration of each PAH is multiplied by a factor which is equal to its carcinogenicity relative to benzo(a)pyrene. The resulting weighted concentrations are summed to calculate the B(a)P-equivalent carcinogenic PAH value. [6, 7]

In addition, the cleanup goals allowed 15% of the treated soil to have a total PAH concentration less than 1,100 mg/kg, and 25% of the treated soil to have a B(a)P-equivalent concentration less than 230 mg/kg. [2, 6]

Additional Information on Goals

At the beginning of this application, soil was classified as RCRA hazardous waste K001. However, in February 1992, soon after full-scale operation began, an LDR treatability variance was obtained so that the soil would not need to be treated to meet the LDR treatment standards for K001. The treatability variance was obtained under 40 CFR Section 268.44, and resulted in the cleanup goals for total and carcinogenic PAHs shown above. Additional information is provided in reference 10 on the process used to obtain the variance. [10, 26]

Treatment Performance Data

Treatment performance data are available from 13 of the 61 bioreactor batches. Slurry samples were collected at the start of biotreatment and on a periodic basis during treatment. The sampling point for slurry samples is marked on Figure 2 with an "X." No additional information on how samples were collected is provided in the available references.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Table 5 presents the initial concentrations of PAHs in the slurry, and Table 6 presents the concentrations of PAHs in the slurry after treatment had occurred. [NOTE: No information is provided in the available references to explain how specific days were selected for use in calculating treatment efficiency - e.g., how Day 10 was selected for calculating treatment efficiency for bioreactor batch R1 B5; what data were used to select this day; or why treatment continued beyond this date.] Tables 5 and 6 show the concentrations of 16 individual PAH constituents measured in each of the bioreactor batches, as well as the sum of the concentrations for all 16 PAHs and for the 7 carcinogenic PAHs, and the B(a)P-equivalent for the sum of the 16 PAHs. The average concentration of each PAH is also shown on these tables. Figures 3 through 8 show the total PAH concentrations as a function of time for the first six batches shown in Tables 5 and 6, based on data in References 2 and 24.

Table 7 presents a summary of the PAH treatment performance data for the first six batches according to the number of rings in the PAH constituent (two, three, four, or five and six ring PAHs). This table shows the cleanup goals for this application, and the average results for PAHs at the start of treatment (from Table 5) and after treatment (from Table 6). The treatment efficiency included in the table was calculated based on the reduction in concentration for these average results.

No data are provided in the available references to characterize the performance of the soil washing step.

Performance Data Assessment

For the 13 batches with available data, the average total PAH concentration was reduced from 8,545 mg/kg to 634 mg/kg, which corresponds to a treatment efficiency of 93 percent. The average B(a)P-equivalent concentration was reduced from 467 mg/kg to 152 mg/kg, or 67 percent. Carcinogenic PAHs showed a similar reduction, from 1,160 mg/kg to 374 mg/kg, or 67 percent.

Table 6 shows that 12 of the 13 bioreactor batches met the cleanup goal of 950 mg/kg for total PAHs; for the 12 batches, total PAH concentrations ranged from 421 mg/kg to 898 mg/kg. For batch R1 B7, the total PAH concentration on Day 20 was 1,126 mg/kg, exceeding the maximum cleanup goal. According to the OSC, further treatment was performed on this batch, however, additional data on treatment performance for this batch are not provided in the available references. [26]

Table 5. Concentrations of PAHs in Slurry at Start of Treatment [2, 24]

Constituent	Bioreactor/Batch ID#												
	R1 B5	R1 B8	R1 B9**	R1 B10	R2 B9	R2 B10	R1 B4	R1 B6	R1 B7	R2 B5	R2 B6	R2 B7	R2 B8
	Concentration (mg/kg Dry Weight)												
Acenaphthene	642	968	692	892	1,280	981	465	574	723	508	1,440	846	949
Acenaphthylene	34	ND (163)	28	ND(59)	ND(223)	ND(51)	ND(155)	37.2	31.9	ND(50.5)	ND(373)	ND (67.1)	ND(120)
Anthracene	1,050	1,560	2,140	2,280	2,340	2,330	1,540	1,720	1,620	1,580	2,870	2,020	1,490
Benzo(a)anthracene[c]	224	287	283	237	370	277	327	279	230	245	597	241	279
Benzo(b)fluoranthene[c]/ Benzo(k)fluoranthene*[c]	367	337	278	296	345	304	233	323	344	290	710	287	349
Benzo(ghi)perylene	21	ND (163)	33	ND(59)	ND(223)	ND(51)	ND(155)	ND(32.7)	20.8	ND(50.5)	ND(373)	ND (67.1)	ND(120)
Benzo(a)pyrene[c]	92	ND (163)	105	100	ND(223)	98	ND(155)	98.2	87.4	81.5	ND(373)	94.7	ND(120)
Chrysene[c]	228	302	301	247	397	302	316	297	254	225	573	257	310
Dibenzo(ah)anthracene[c]	15	ND (163)	ND(40)	ND(59)	ND(223)	ND(51)	ND(155)	ND(32.7)	14.6	ND(50.5)	ND(373)	ND (67.1)	ND(120)
Fluoranthene	1,060	1,570	1,950	1,850	2,210	1,610	1,590	1,850	1,260	1,490	3,470	1,810	1,630
Fluorene	181	669	499	661	1,040	732	195	204	663	281	483	850	833
Indeno(1,2,3-cd)pyrene[c]	30	ND (163)	40	ND(59)	ND(223)	ND(51)	ND(155)	35.4	28.2	ND(50.5)	ND(373)	ND (67.1)	ND(120)
Naphthalene	19	ND (163)	ND(40)	ND(59)	ND(223)	ND(51)	ND(155)	ND(32.7)	24.7	ND(50.5)	ND(373)	87.3	ND(120)
Phenanthrene	220	1,250	395	2,030	1,300	988	253	279	1,360	272	639	2,710	1,680
Pyrene	878	1,080	1,220	1,010	1,610	1,090	1,130	1,270	974	950	2,430	989	1,080
Total PAHs	5,061	8,512	8,004	9,751	11,561	8,840	6,694	7,016	7,636	6,023	14,331	10,326	8,960
Total Carcinogenic PAHs	956	1,171	1,027	939	1,447	1,032	1,109	1,049	958	892	2,440	947	1,118
Benzo(a)pyrene Equivalent	245	585	295	334	818	318	570	268	245	283	1,313	349	454

[c]Carcinogenic PAHs.
*Sum of b and k isomers reported.
**The vendor specified that some concentration values were estimated for this batch. However, which values were estimated was not specified.
ND - Not detected. Value in parentheses is the reported detection limit. For calculation of averages and totals, ½ the detection limit was used for values that were not detected.

Table 6. Concentrations of PAHs in Slurry After Treatment [2, 24]

Constituent	Bioreactor/Batch ID#												
	R1 B5 Day 10	R1 B8 Day 13	R1 B9 Day 10	R1 B10 Day 10	R2 B9 Day 11	R2 B10 Day 27	R1 B4 Day 33	R1 B6 Day 11	R1 B7 Day 20	R2 B5 Day 20	R2 B6 Day 17	R2 B7 Day 13	R2 B8 Day 23
	Concentration (mg/kg Dry Weight)												
Acenaphthene	ND(7)	ND(14)	ND(16)	9	ND(7)	ND(13)	ND(11.3)	ND (6.06)	ND (34.5)	ND (10.3)	ND(27.3)	ND(12.3)	ND(22.7)
Acenaphthylene	11	13	ND(16)	19	14	23	12.1	6.63	ND (34.5)	10.5	ND(27.3)	ND(12.3)	ND(22.7)
Anthracene	104	55	102	230	135	100	115	125	229	84.1	39.6	89.3	68.2
Benzo(a)anthracene[c]	10	ND(14)	ND(16)	20	10	16	16.5	ND (6.06)	ND (34.5)	12	ND(27.3)	ND(12.3)	ND(22.7)
Benzo(b)fluoranthene[c]/ Benzo(k)fluoranthene*[c]	155	240	131	254	259	213	138	95	476	149	282	166	226
Benzo(ghi)perylene	23	26	25	ND(7)	ND(7)	29	22	13.9	ND (34.5)	18	ND(27.3)	14.8	ND(22.7)
Benzo(a)pyrene[c]	52	80	74	95	91	82	63.6	46	83.4	38.9	82.9	49.8	70.6
Chrysene[c]	24	55	30	41	33	31	57.1	31.1	69.6	18.2	61.6	33.8	57.4
Dibenzo(ah)anthracene[c]	10	ND(14)	ND(16)	ND(7)	ND(7)	20	ND(11.3)	ND (6.06)	ND (34.5)	ND (10.3)	ND(27.3)	ND(12.3)	ND(22.7)
Fluoranthene	25	32	26	31	37	43	41.3	21	40.2	37	26	21.4	24.9
Fluorene	14	ND(14)	ND(16)	25	16	15	ND(11.3)	16.2	ND (34.5)	ND (10.3)	ND(27.3)	ND(12.3)	ND(22.7)
Indeno(1,2,3-cd)pyrene[c]	28	33	31	31	24	40	28.3	17.9	ND (34.5)	23.6	33.1	19	30.7
Naphthalene	ND(7)	ND(14)	ND(16)	9	ND(7)	ND(13)	ND(11.3)	ND (6.06)	ND (34.5)	ND (10.3)	ND(27.3)	ND(12.3)	ND(22.7)
Phenanthrene	27	14	23	79	30	31	22.3	24.6	53.9	19.9	11.3	20.7	15.9
Pyrene	25	18	30	48	46	33	40.4	11.7	36.2	29	14.7	28	17
Total PAHs	515	601	520	898	709	689	579	421	1,126	461	646	480	591
Total Carcinogenic PAHs	279	422	282	445	421	402	309	196	681	247	487	281	407
Benzo(a)pyrene Equivalent	123	144	133	146	140	211	112	74	224	84	185	249	156

[c]Carcinogenic PAHs.
*Sum of b and k isomers reported.
ND - Not detected. Value in parentheses is the reported detection limit. For calculation of averages and totals, ½ the detection limit was used for values that were not detected.

Table 7. Summary of PAH Treatment Performance Data [2]

Constituent	Cleanup Goal (mg/kg)	Average Concentration at Outset of Treatment*** (mg/kg)	Average Concentration After Treatment*** (mg/kg)	Treatment Efficiency (%)
Two Ring PAHs				
Naphthalene	N/A	48	6	88
Three Ring PAHs				
Acenaphthene	N/A	909	6	99
Acenaphthylene	N/A	52	15	71
Anthracene	N/A	1,950	121	94
Fluorene	N/A	630	14	98
Phenanthrene	N/A	1,031	34	97
Four Ring PAHs				
Benzo(a)anthracene*	N/A	280	12	96
Chrysene*	N/A	296	36	88
Fluoranthene	N/A	1,708	32	98
Pyrene	N/A	1,148	33	97
Five and Six Ring PAHs				
Benzo(b)fluoranthene*	N/A	321	209	35
Benzo(k)fluoranthene*	N/A	**	**	**
Benzo(ghi)perylene	N/A	50	18	64
Benzo(a)pyrene*	N/A	98	79	19
Dibenzo(ah)anthracene*	N/A	47	9	81
Indeno(1,2,3-cd)pyrene*	N/A	53	31	42
Total PAHs	950	8,621	655	92
Carcinogenic PAHs	N/A	1,095	376	66
Benzo(a)pyrene Equivalent	180	433	150	65

*Carcinogenic PAHs.
**Combined with benzo(b)fluoranthene.
***Concentration values are averages from first six batches shown on Tables 5 and 6, and are reported as mg/kg dry weight.
N/A - Not applicable. No cleanup goal established for this constituent/group of constituents.

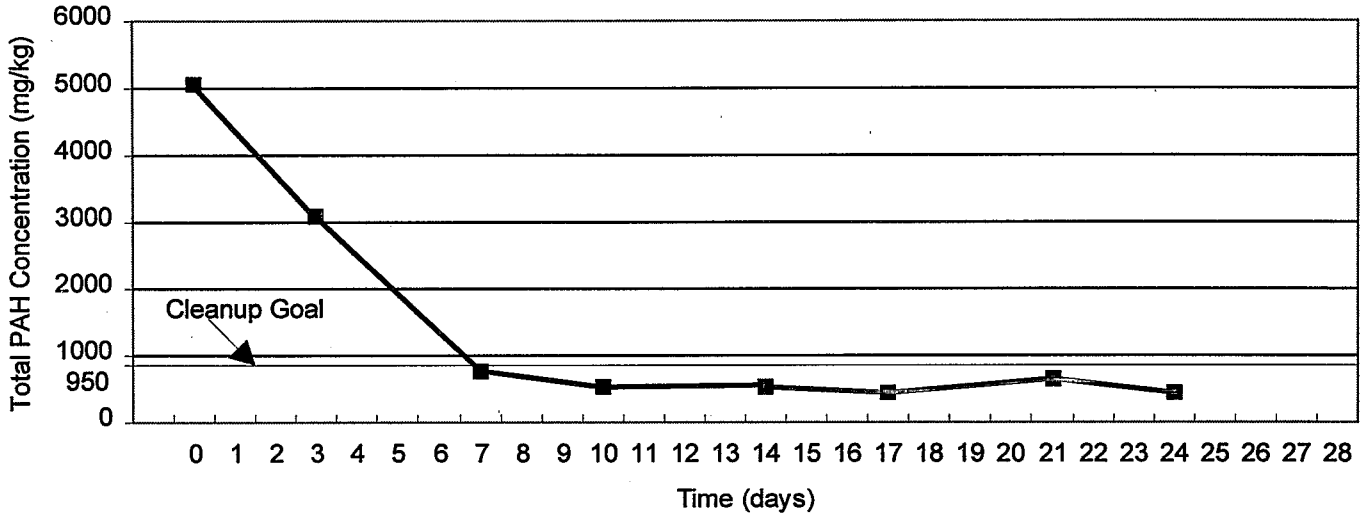

Figure 3. Total PAH Concentration vs. Time
Bioreactor/Batch R1 B5 [2]

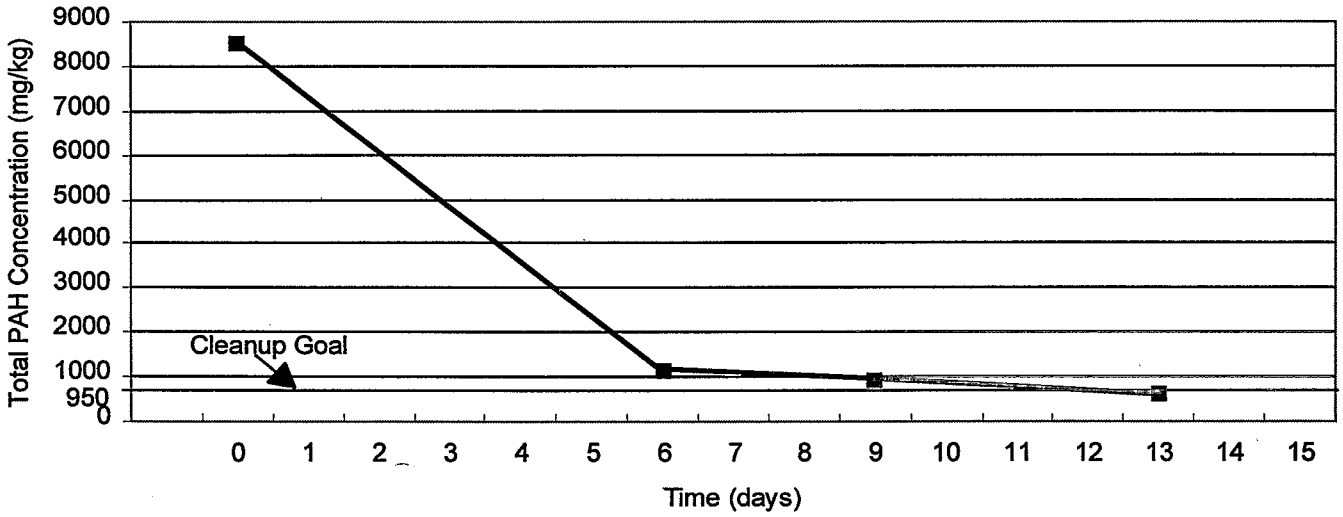

Figure 4. PAH Concentration vs. Time
Bioreactor/Batch R1 B8 [2]

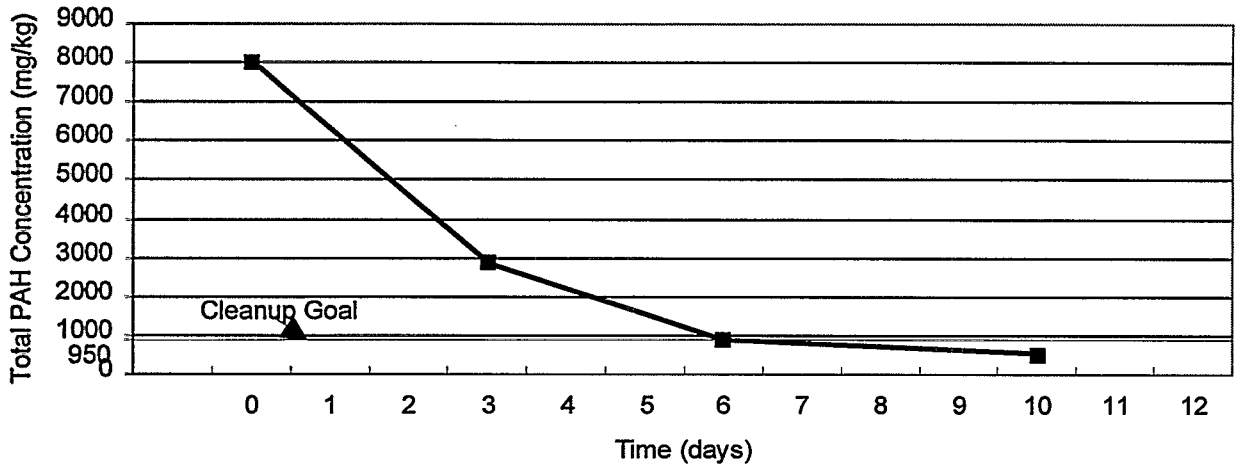

Figure 5. PAH Concentration vs. Time
Bioreactor/Batch R1 B9 [2]

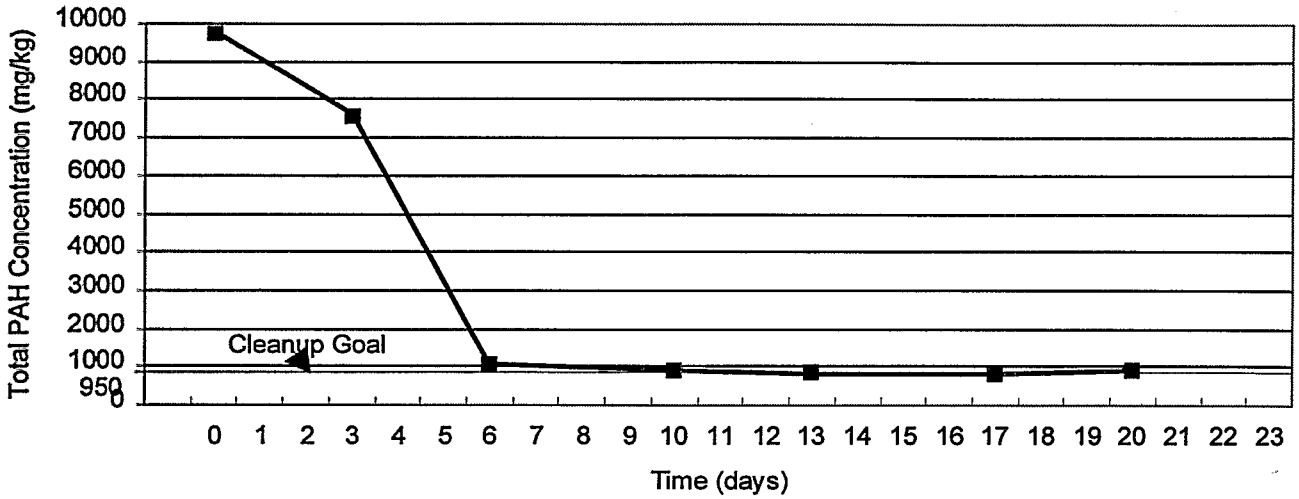

Figure 6. PAH Concentration vs. Time
Bioreactor/Batch R1 B10 [2]

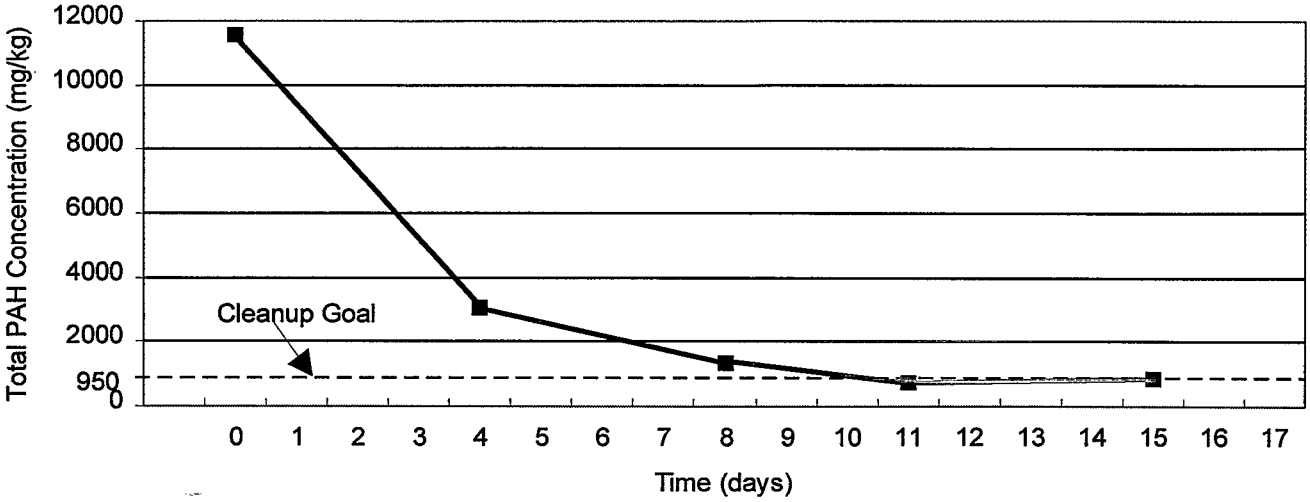

Figure 7. PAH Concentrations vs. Time
Bioreactor/Batch R2 B9 [2]

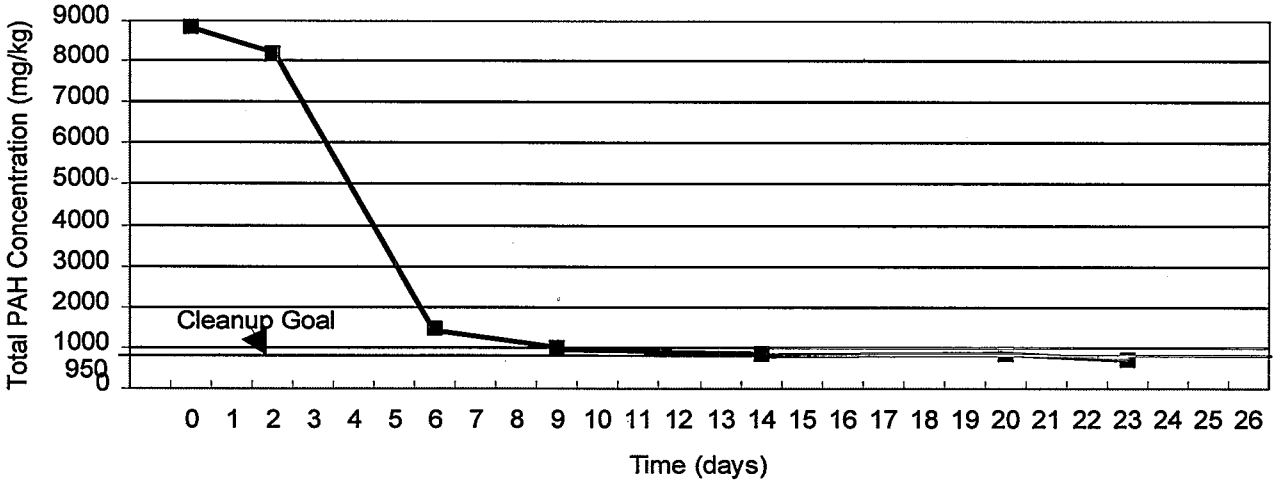

Figure 8. PAH Concentrations vs. Time
Bioreactor/Batch R2 B10 [2]

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (cont.)

Nine of the 13 batches met the cleanup goal of 180 mg/kg for B(a)P-equivalent; the batches that met the cleanup goal ranged from 24 to 156 mg/kg. According to the OSC, further treatment was also performed on the four batches that did not appear to meet the cleanup goal for B(a)P (R2 B20 at 211 mg/kg; R1 B7 at 224 mg/kg; R2 B6 at 185 mg/kg; and R2 B7 at 249 mg/kg). However, additional data on treatment performance for these batches are not provided in the available references. [26]

As shown in Figures 3 through 8, the majority of the biodegradation occurred during the first 5 to 10 days of treatment, and the cleanup goal for total PAHs was met for 12 of the 13 batches within approximately 19 days of treatment.

The data in Table 7 show that the number of ring structures in the PAH constituent (two, three, four, or five and six rings) affected the treatment efficiency. The concentrations of constituents with two to four rings were reduced 71% to 99%, while five and six ring constituents were reduced 19% to 81%. These results are consistent with reports in the technical literature that show that higher molecular weight PAHs (e.g., five and six ring structures) are more difficult to biodegrade than two to four ring structures. [8]

Performance Data Completeness

Analytical data for 16 PAHs are available for 13 of the 61 batches processed through the treatment system during the course of remediation. Data are available for specific days during each batch treatment, as well as for the range of operating conditions over the course of the treatment application.

Performance Data Quality

Limited information is contained in the available references on performance data quality. A quality assurance program plan (QAPP) for this application was developed by a commercial analytical laboratory (Analytical Services Corp.). The QAPP addressed project organization and responsibilities, QA objectives, sampling procedures, sample custody, analytical procedures, and other items.

PAH slurry samples were centrifuged and extracted following SW846 Method 3540. PAH concentrations were quantified using gas chromatography with a mass spectrometer detector following SW846 Method 8270. As shown in Appendix A, detection limits for individual PAHs ranged from 5 mg/kg to 223 mg/kg for the first six batches shown in Table 5 for this application.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Quality (cont.)

The vendor noted two problems related to performance data quality for this application. Problems were noted concerning implementation of the sampling plan, and for sample extraction and quantification. These problems were resolved by developing an approved sampling plan, and by performing audits on the extraction and analytical methodology.

According to the OSC, the vendor evaluated two potential methods for PAH sample extraction (soxhlet and sonic extraction) and found "significant differences" in analytical results based on method used. Based on these results, the analytical method was standardized and written into the contract. [26]

TREATMENT SYSTEM COST

Procurement Process

The contract for remediation services at Southeastern Wood was competitively procured by EPA. For this procurement, EPA's Contracting Officer (CO) obtained a deviation from the EPA Acquisition Regulations which allowed a negotiated procurement without submission of technical proposals. Performance specifications were used instead of specifying a technology. Twelve bidders submitted proposals for different technologies and price was the determining factor for award. The contract was awarded to OHM Remediation Services Corporation. EPA required the vendor to perform a technology demonstration at the site to ensure that the technology would be feasible. The contract with OHM was a firm fixed price (lump sum) service contract. Additional information on the procurement process for this application is provided in Reference 4. [4]

Treatment System Cost [1, 2, 12]

Tables 8 and 9 present the costs for the slurry phase bioremediation treatment application at Southeastern Wood. In order to standardize reporting of costs across projects, costs are shown in Tables 8 and 9 according to the format for an interagency Work Breakdown Structure (WBS). The WBS specifies 9 before-treatment cost elements, 5 after-treatment cost elements, and 12 cost elements that provide a detailed breakdown of costs directly associated with treatment. Tables 8 and 9 present the cost elements exactly as they appear in the WBS, along with the specific activities as provided by the treatment vendor.

As shown in Table 8, the vendor provided actual cost data that shows a total of $2,400,000 for activities directly associated with treatment of 14,140 tons (10,500 cubic yards) of soil and sludge (i.e., excluding after-treatment cost elements). This total consists of costs for mobilization/setup, startup/testing/permits, and operation. Included in this total are costs for treatment of 61 batches at $18,700 per batch. The total costs for activities directly attributed to treatment corresponds to $170 per ton ($230 per cubic yard) of soil and sludge treated. In addition, the vendor provided cost data that show a total of $500,000 for after-treatment activities (site preparation and closure). The vendor provided no information on before-treatment activities, such as for monitoring, sampling, testing, and analysis in this application. [3, 19]

Table 10 shows actual costs provided by the vendor for slurry preparation, slurry phase biological treatment, and dewatering on a per ton of material basis. This table shows that the relatively largest costs associated with this system are for the slurry preparation process. [1]

TREATMENT SYSTEM COST (CONT.)

Treatment System Cost (Cont.)

Table 8. Treatment Activity Cost Elements According to the WBS* [3]

Cost Elements (Directly Associated With Treatment)	Cost ($)	Actual or Estimated (A) or (E)
Mobilization/Set Up (Design Engineering)	100,000	A
Startup/Testing/Permits (Treatability and Pilot-Scale Testing)	200,000	A
Operation (short-term - up to 3 years) (soil screening and slurry preparation, slurry treatment, slurry dewatering, and project administration and support)	2,100,000	A
TOTAL TREATMENT ACTIVITY COST	2,400,000	A

Table 9. After-Treatment Cost Elements According to the WBS* [3]

Cost Elements	Cost ($)	Actual or Estimated (A) or (E)
Site Restoration (site preparation and closure)	500,000	A
TOTAL AFTER-TREATMENT COST	500,000	A

Table 10. Unit Costs for Treatment of Soil and Sludge at Southeastern Wood Preserving Superfund Site [1]

Process	Cost per Dry Ton of Material Treated ($)	Actual or Estimated (A) or (E)
Slurry Preparation	50 - 60	A
Slurry Phase Biological Treatment	40 - 55	A
Dewatering Process	20 - 30	A
Total for Slurry Phase Biological Treatment System	110 - 145	A

*Cost figures rounded up to the nearest $100,000.

TREATMENT SYSTEM COST (CONT.)

Cost Data Quality

The cost data presented above are actual costs for this application as reported by the treatment vendor, and are believed to accurately represent the costs associated with this application.

Vendor Input

The vendor specified three variables that have a significant impact on the cost of remediation using this technology: the slurry phase reactor solids concentration, residence time in the reactors, and the percentage of material removed in the slurry preparation/soil washing process. According to the vendor, increasing the solids concentration in the reactors increases the amount of soil treated per batch. This results in a decrease both in the total number of batches treated and the cost per ton of treatment. In addition, longer batch residence times reduce the system throughput and, therefore, increase the cost of treatment. The higher the percentage of material that is removed by the slurry preparation/soil washing process, the lower the cost for the bioreactors, since less material will remain to be biologically treated. [3]

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- The total project cost for slurry phase bioremediation at Southeastern Wood, including treatment, design engineering, treatability and pilot-scale testing, site closure, and project administration was $2,900,000. Of the total, $2,400,000 were for costs directly attributed to treatment, and $500,000 were for after-treatment activities.

- The $2,400,000 for costs directly attributed to treatment corresponds to $170 per ton ($230 per cubic yard) of soil and sludge treated.

- According to the OSC, this treatment process, which combined soil washing with biotreatment, would be more cost-effective at a site with 50 to 60% sand than at Southeastern Wood, which had only 10-15% sand. At a site with 50% sand, the waste volume would be cut in half, reducing the amount which had to be biotreated.

- According to the OSC, the treatment vendor invested significant amounts of time and resources for research and development on this application, including extensive treatability testing.

Performance Observations and Lessons Learned

- Cleanup goals for total PAHs and B(a)P-equivalent PAHs were met in this treatment application. The cleanup goal for total PAHs was specified as 950 mg/kg and for B(a)P-equivalent PAHs as 180 mg/kg, with allowances for a portion of the treated soil to be at levels slightly greater than these values.

- For the 13 bioreactor batches with available data, the average total PAH concentration was reduced from 8,545 mg/kg to 634 mg/kg, which corresponds to a treatment efficiency of 93 percent. The average B(a)P-equivalent concentration was reduced from 467 mg/kg to 152 mg/kg, or 67 percent. Carcinogenic PAHs showed a similar reduction from 1,160 mg/kg to 374 mg/kg or 67 percent.

- Biodegradation primarily occurred during the first 5 to 10 days of treatment, and the cleanup goal for total PAHs in 12 of 13 batches was met within approximately 19 days of treatment.

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Performance Observations and Lessons Learned (cont.)

- The number of ring structures in the PAH constituent were found to affect treatment efficiency. Concentrations of constituents with two to four rings were reduced 71% to 99%, while five and six ring constituents were reduced 19% to 81%. These results are consistent with reports in the technical literature that show that higher molecular weight PAHs (e.g., five and six ring structures) are more difficult to biodegrade than two to four ring structures.

- Temperature was identified by the vendor as a factor which affected degradation rates. Degradation was slower during the winter months than during the spring, summer, and fall.

Other Observations and Lessons Learned

- According to the OSC, the design of the treatment system was modified significantly from the original plans, including addition of a desanding process. At the beginning of full-scale operation, the vendor found that keeping sand-sized particles in suspension in the reactors was extremely difficult, and therefore they removed the sand prior to pumping the slurry to the reactors.

- According to the vendor, there were several problems with the operation of this technology. These included foam production in the bioreactors during this application. Foam would overflow the bioreactors, and the vendor had trouble containing the overflow. The problem was resolved by revising the combination of dispersant and defoamers used in the slurry preparation, including adding a lignin. In addition, the vendor had problems with treating the soil to meet the K001 treatment standard of 1.5 mg/kg for pyrene and phenanthrene. This problem was resolved by modifying the cleanup standards to be based on total PAH concentrations (i.e., the sum of 16 specific PAHs) instead of individual constituent standards.

- According to the vendor, there were variations caused by sampling and analytical methods in this application. According to the OSC, the vendor evaluated two potential methods for PAH sample extraction (soxhlet and sonic extraction) and found "significant differences" in analytical results based on method used. Based on these results, the analytical method was standardized and written into the contract.

- To assess emissions of VOCs and PAHs from the bioremediation process, the treatment vendor performed air dispersion modelling. The vendor modelled off-property ground-level VOC and PAH concentrations using the EPA Industrial Source Complex (ISC) dispersion simulation model. The results of the modelling showed that proposed

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Other Observations and Lessons Learned (cont.)

activities would not result in any exceedence of accepted long-term exposure screening levels for this application.

- According to the OSC, soil in the slurry dewatering unit was very soft and could not have supported equipment to till the soil. Therefore, while post slurry-treatment using land treatment was considered, it was determined that this would not be feasible without amending the soil to increase its bearing capacity. Therefore, land treatment was not performed.

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Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Radian International under EPA Contract No. 68-W3-0001 and U.S. Army Corps of Engineers Contract No. DACA45-96-D-0016.

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

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		

Case Study Abstract

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.

Executive Summary

This report documents the cost for the first full-scale use of windrow composting to remediate explosives-contaminated soils. The results of this cost report will allow managers of other sites with explosives-contaminated soils to estimate the cost of remediation using the windrow composting technology, assuming similar site-specific variables. Estimates for sites with different site conditions (e.g., nature and extent of contamination, soil type, climate) and remedial action goal must scale subelement costs according to individual site characteristics.

The 1992 Remedial Investigation and Feasibility Study (RI/FS) for the Umatilla Army Depot Activity (UMDA), located in Hermiston, Oregon, concluded that although both incineration and composting constitute technically effective remediation methods for reducing explosives concentrations in soils, windrow composting appears to be more cost-effective based on preliminary trial tests and small-scale demonstration data (9). As a result, the 1992 Record of Decision selected windrow composting to remediate contaminated soils from two munitions washout lagoons at UMDA.

The remediation effort at UMDA was performed in two phases by two separate contractors. Phase I work included excavation of the contaminated soils from the lagoons, erection of a soil storage building, and stockpiling of the excavated soil in the storage building. Phase II work included preparation of three trial tests to determine the optimal amendments mixture, full-scale production composting, demobilization, and site restoration. The total volume of soil excavated and subsequently remediated was 10,969 cubic yards. This total soil volume is an increase of 40 percent over the original estimated 6,339 cubic yards.

This cost report concludes that windrow composting costs $346 per ton of contaminated soil at UMDA. This unit cost is based on all costs associated with Phase I and Phase II and does not include U.S. Army Corps of Engineers (USACE) cost for support and contracts. Explosives concentrations were as high as 88,000 parts per million (ppm) for TNT and 1,900 ppm for RDX before treatment. The 1992 Record of Decision, which presents the selected remedial action, specifies the cleanup goal of <30 ppm each for TNT and RDX. Both TNT and RDX achieved explosives reduction after treatment to below the 30 ppm cleanup limit.

This report presents cost data using the Remedial Action-Work Breakdown Structure (RA-WBS), the standard cost methodology for remediation work accepted by the Federal Remediation Technologies Roundtable, which includes the U.S. Department of Energy, the U.S. Environmental Protection Agency, the U.S. Department of the Interior, and the U.S. Department of Defense. The three largest cost elements for the remediation project at UMDA, in order, are:

Table ES-1. Summary of Largest Cost Elements

WBS Item	Activity	% of Total Phase I and Phase II Cost
33.11	Biological Treatment	39%
33.01	Mobilization and Preparatory Work	25%
33.03	Site Work	10%

The USACE cost for support (engineering, supervision, administration) and contracts (Invitation for Bid and Request for Proposal) was also significant at 21 percent of total project cost (Phase I plus Phase II plus USACE cost). The USACE cost for support and contracts represents a fixed cost; that is, this cost is independent of project duration or volume of contaminated soil to be treated. Mobilization & Preparatory Work and Site Work (e.g., clearing and grubbing) also represent fixed costs at UMDA because the costs do not vary with soil volume. Although Site Work is a fixed cost at UMDA, this cost will vary at other sites given different site conditions (e.g., vegetation, site area, topography). Biological Treatment, however, is a variable cost because its subelement costs will vary according to site specific conditions (e.g., nature and extent of contamination, soil type, climate, regional labor rates, amendments availability) and the remediation goal (e.g., extent of explosives reduction, volume of contaminated soil).

1.0 Introduction

1.1 Purpose

The purpose of this report is to present the cost data for the first full-scale use of windrow composting to treat explosives-contaminated soils at the Umatilla Army Depot Activity (UMDA) in Hermiston, Oregon. The results of this report will allow managers of other explosives-contaminated sites to evaluate the cost benefits of using windrow composting and estimate the cost for remediation using this technology for treatment. Although preliminary economic analyses and pilot scale demonstrations of windrow composting have been completed to indicate cost savings and explosives reduction, this report documents actual field cost data from a full-scale remediation effort. Cost data are presented using the Remedial Action Work Breakdown Structure (RA-WBS), a standard cost methodology for remediation work accepted by the Federal Remediation Technologies Roundtable, which includes the U.S. Department of Energy, the U.S. Environmental Protection Agency, the U.S. Department of Interior, and the U.S. Department of Defense. The RA-WBS identifies project-specific cost elements (either fixed or variable, defined in section 4.2.1) that can be scaled to estimate costs at other sites considering the use of windrow composting to remediate explosives-contaminated soil. In addition to documenting cost, this report offers some recommendations to optimize overall cost at other sites.

1.2 Scope

This report documents the costs associated with the first full-scale use of windrow composting to treat explosives-contaminated soils at UMDA. The UMDA Record of Decision directed the U.S. Army Corps of Engineers (USACE) to apply windrow composting to remediate the explosives-contaminated soils from two washout lagoons at UMDA. Cost data presented in this report were provided by the USACE contractors performing the excavation and remediation.

This report does not include a comparative evaluation of this innovative technology against other treatment methods, including incineration, but it is important to note the unit cost of incineration in order to confirm the cost effectiveness of windrow composting. Historically, incineration has been the selected method of treatment, effective in destroying 99.99 percent of explosive contaminants (9). However, incineration is costly at $740 per ton for treating less than 10,000 tons of soil (4). The unit cost of incineration decreases with increased soil volume to be treated due to high up-front capital costs. Preliminary studies for windrow composting show that it can be 97 to 99 percent effective in destroying explosive contaminants and be cost-effective at an estimated $326 per ton for 10,000 tons of contaminated soil over a project duration of 2 years (8). This report uses actual cost data to identify unit cost (dollars per ton of contaminated soil).

2.0 Background Information

A Remedial Investigation and Feasibility Study (RI/FS) was prepared in 1992 by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), now the U.S. Army Environmental Center (USAEC), to evaluate alternative methods for remediating explosives-contaminated soils at UMDA. This initiative was undertaken in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986, commonly referred to as Superfund, to gather information and initiate the cleanup process. The RI/FS concluded that although both incineration and composting are effective methods for reducing explosive concentrations in the contaminated soils to acceptable levels, composting using a windrow system is more cost-effective than incineration for the situation at UMDA. A September 1992 Record of Decision (ROD) selected windrow composting to remediate the contaminated soils from two washout lagoons at UMDA.

2.1 Site History

UMDA was established in 1941 as an Army ordnance depot to store and handle munitions. UMDA operated an onsite explosives washout plant from the 1950s until 1965. The plant processed munitions to remove and recover explosives using a pressurized hot water system. Water used in the washout process was recycled during plant operation, and the washout system was flushed and drained weekly. The spent washwater was then discharged into two adjacent infiltration/evaporation lagoons, an acceptable industrial practice at that time. An estimated 85 million gallons of effluent were discharged into the lagoons during the period of plant operation. Residual explosives contained in the washwater were later found to have contaminated the soil and groundwater under the lagoons. The lagoons were placed on the National Priorities List (NPL) in 1987.

2.1.1 Site Description

UMDA occupies nearly 20,000 acres of land and straddles Umatilla and Morrow counties in northeastern Oregon (Figure 2-1). The contaminated lagoons, designated the north and south lagoons, are located in a depression in the central part of UMDA (Figure 2-2) and are rectangular in shape. The north lagoon measures 51 feet by 98 feet at the top and 39 feet by 80 feet at the bottom. The south lagoon measures 42 feet by 98 feet at the top and 27 feet by 80 feet at the bottom. All measurements are approximate. The sides are sloped approximately 35 degrees. Both lagoons are approximately 6 feet deep, with sandy bottoms and gravel sides. A gravel berm 15 feet wide separates the lagoons. (See Figure 2-3 for dimensions of the lagoons.)

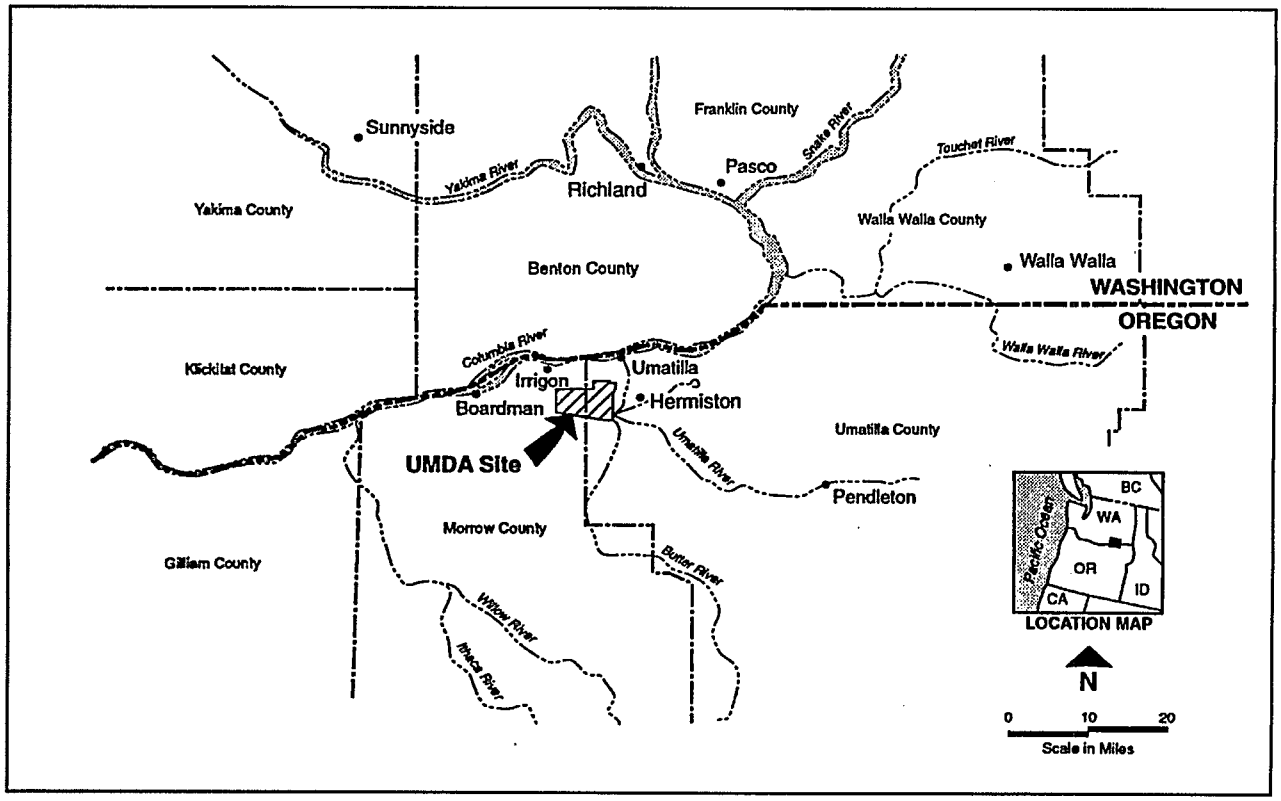

Figure 2-1. Facility Location Map, UMDA

Source: (9)

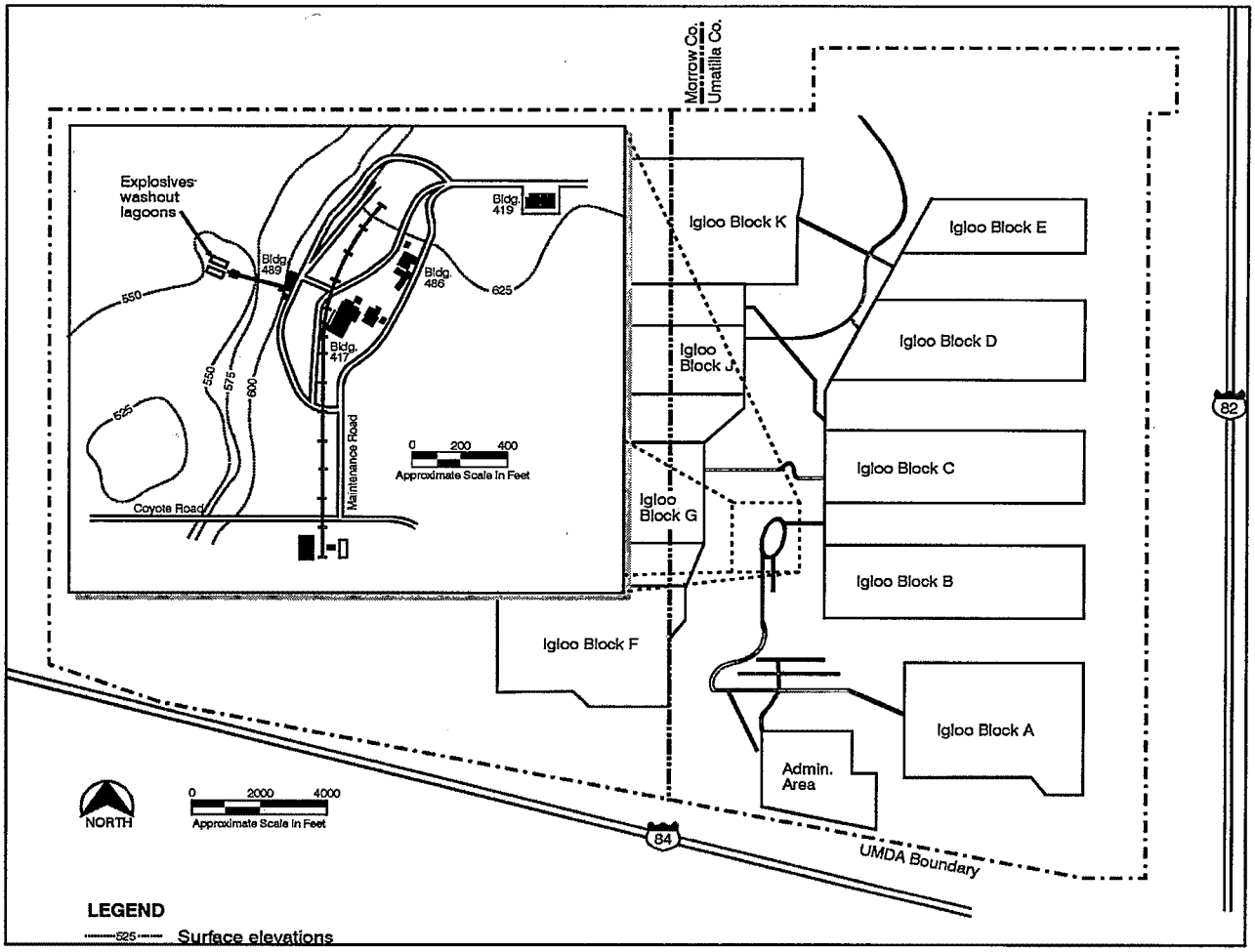

Figure 2-2. Location of Explosives Washout Lagoons, UMDA

Source: (9)

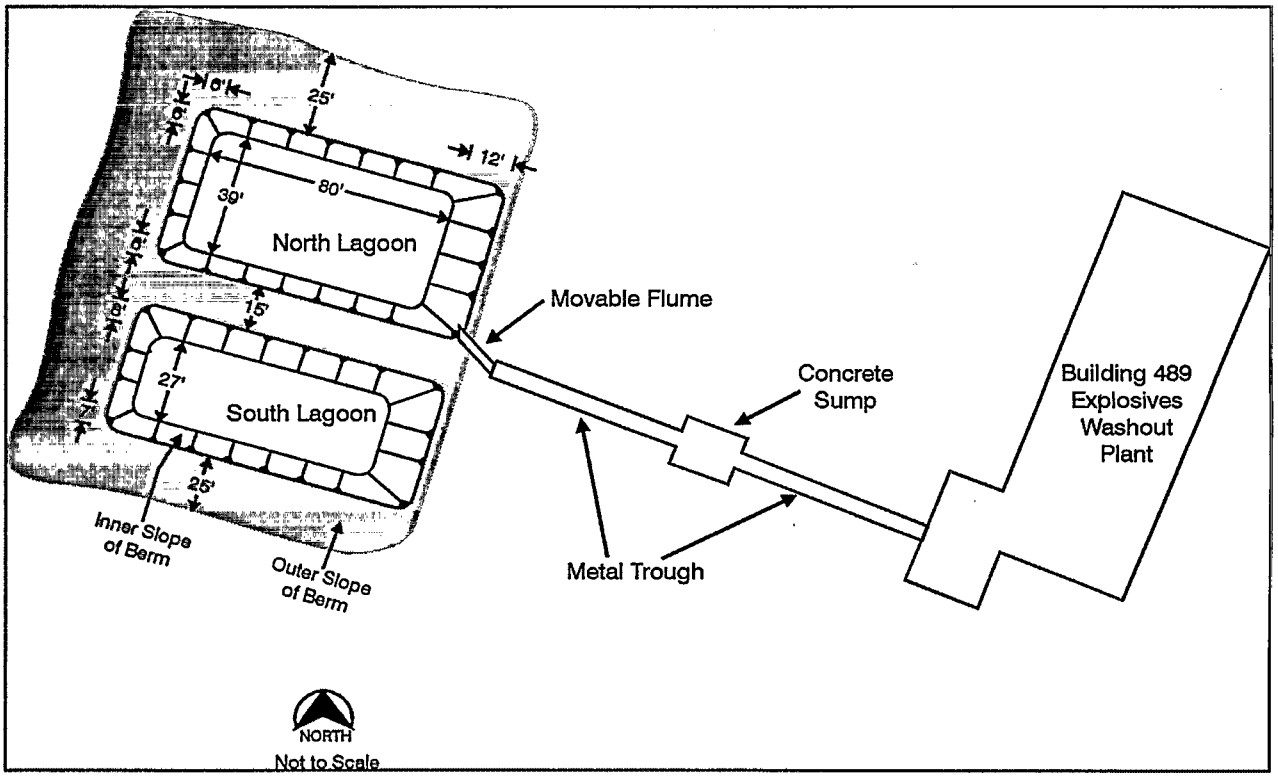

Figure 2-3. Explosives Washout Lagoons and Washout Plant Area, UMDA

Source: (9)

The remainder of this section provides site-specific information on the climatology, soils, surface hydrology, and geology and hydrogeology at UMDA. This information is important in establishing the environmental conditions at UMDA, which will in various degrees affect the determination of cost at other regions.

Climatology

The area is characterized by a semi-arid, cold desert climate (9). Average annual precipitation is 8 to 9 inches, with rainfall occurring mostly between November and March. The evapo-transpiration rate is high, at 32 inches per year. Average temperature at UMDA is 75°F during the summer and 35°F during the winter. Wind data, routinely collected at the Pendleton Municipal Airport, located 30 miles east of the UMDA facility, indicate mean wind speed of 8 to 11 miles per hour with prevailing west and southwest winds.

Soils

The soils surrounding the lagoons are predominantly Quincy fine sand and Quincy loamy fine sand. Quincy fine sand is a very deep, excessively drained soil formed in mixed sand. Soil permeability is high, and water-holding capacity is low. Soil pH gradually increases with depth from about 7 (neutral) to 8.5 (basic) at 5 feet below the ground surface (9). Vegetation is scarce around the lagoons, increasing the risk of wind erosion. Soil organic matter is generally less than 0.5 percent. Quincy loamy fine sand exhibits similar characteristics. Found on slightly flatter slopes, it has slightly more silt and clay in the upper layer, resulting in a higher water holding capacity than Quincy fine sand.

Surface Hydrology

There are no perennial streams within the UMDA facility because of the high permeable nature of the soils. Runoff is diverted away from the lagoons by the raised berms, and any water collected in the lagoons infiltrates very quickly. Surrounding rivers include the Columbia River, located approximately 3 miles north of the northern boundary of UMDA, and the Umatilla River, located approximately 1 to 2 miles east of UMDA (9).

Geology and Hydrogeology

The geology at UMDA is characterized by three distinct geological units: unconsolidated glacial flood gravels (alluvium), which range in thickness from 50 feet to 154 feet in areas surrounding the lagoons, based on topographic variation; cemented basalt gravel/weathered basalt, ranging in thickness from 14 feet to 28 feet, with underlying gravels 30 to 50 feet thick; and basalt, which ranges in thickness of 89 feet to 106 feet (9).

The depth to groundwater varies seasonally, from 44 feet to 49 feet below the bottom of the lagoons. Groundwater flows predominantly towards the northwest. Groundwater well sampling indicate low levels of explosives contamination from the lagoons. Groundwater treatment is being evaluated separately (9).

2.1.2 Contaminants of Concern

The principal explosives from the munitions were—

- 2,4,6-Trinitrotoluene (TNT);
- Hexahydro-1,3,5-trinitro-1,3,5-triazine (commonly referred to as Royal Demolition Explosive or RDX);
- Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (commonly referred to as High Melting Explosive or HMX); and
- 2,4,6-Trinitrophenylmethylnitramine (Tetryl).

The munitions also contained 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), trinitrobenzene (TNB), dinitrobenzene (DNB), and nitrobenzene (NB), occurring as either impurities or degradation products of TNT.

Contamination by TNT, RDX, HMX, TNB, and 2,4-DNT were most frequently detected in the soil. TNT and RDX concentrations were highest, typically ranging from 100 to 2,000 parts per million (ppm) to a depth of 3.5 feet and generally less than the cleanup level of <30 ppm below 3.5 feet. The maximum concentration of TNT was detected in the top inch of soil at 88,000 ppm. HMX concentrations ranged from below detection (<1 ppm) to 100 ppm at a depth of 4 to 6 feet. TNB concentrations ranged from 2 ppm to 47 ppm, while 2,4-DNT concentrations were low (below detection [<1 ppm] to 5 ppm). Tetryl, 2,6-DNT, DNB, and NB were rarely if ever detected, and then only at low (<5 ppm) concentrations.

The 1992 ROD which presented the selected remedial action, in accordance with CERCLA, for the Explosive Washout Lagoons Soils at UMDA specifies the reduction of TNT and RDX concentrations of 30 ppm or less for each contaminant. Because of the much lower concentrations and total quantities of the other contaminants, they were not considered in establishing remedial goals. Previous studies have also shown that reduction of TNT and RDX indicate a commensurate reduction of other explosives to levels which would pose no significant risk to human health and the environment.

2.2 Technology Description

Composting is a natural process in which microorganisms biologically degrade organic materials under controlled conditions. The main advantage of composting, as compared to incineration, is cost. Composting also minimizes the risk of releasing hazardous products into the atmosphere. Both of these attributes make it a more acceptable remediation approach to public stakeholders. Composting has been performed for many years for the treatment of municipal waste and wastewater sludges, but its application to explosives-contaminated soils is innovative.

Composting is initiated by mixing biodegradable organic matter with bulking agents and other amendments. Bulking agents (e.g., sawdust, wood shavings) enhance the porosity of the mixture to be composted while amendments, such as agricultural and animal waste, provide nutrients to sustain microbial growth. The use of bulking agents can significantly increase the final volume of targeted material, which may have an impact on its redistribution at the site if space is limited. Composting usually occurs under aerobic (with oxygen), thermophilic (temperatures ranging from 55°C to 60°C) conditions. Other control parameters (besides oxygen content and temperature) are moisture content, compost pH, type and concentration of organic constituents, and concentration of inorganic nutrients (e.g., nitrogen and phosphorus).

In composting using a windrow system, the soil and amendment mixture are formed into elongated piles (windrows) on an impervious surface and turned periodically. Windrows are typically 4 to 6 feet high and 10 to 12 feet wide, with length of the windrow determined by the size constraints of the pad surface or work area. The windrow piles are mechanically turned on a regular basis to aerate the mixture, distribute heat and moisture, and ensure even composting. The next chapter (Chapter 3) details the application of windrow composting at UMDA.

2.3 Project Description

The remediation project, supported by USACE, was conducted in two phases. The phased procurement approach employed at UMDA came about, in part, because of a requirement imposed by CERCLA which stipulates that physical onsite remedial action must begin within 15 months of the issuance of the ROD which was signed in September 1992. Pressed with the possibility of receiving a Notice of Violation (NOV) and other penalties if the deadline was not met, the USACE opted to divide the project into two phases. Phase I would cover the routine excavation and construction portion and be offered in the faster Invitation for Bid (IFB) solicitation format while Phase II, which would cover the entire remediation process, would be offered using the more lengthy Request for Proposal (RFP) solicitation process. By dividing the remediation work effort, USACE was successfully able to prepare and award the IFB for Phase I prior to the deadline, thereby effectively negating any associated violation or penalty. However, this contracting strategy also introduced some duplication of effort (and therefore, costs), given that two contracts now existed where only one had originally been envisioned.

Phase I, which has been completed, was performed by Wilder Construction Company and included the excavation of the soils from the lagoons, erection of a soil storage building, and stockpiling of the excavated soils in the storage building. Phase II, which is currently under way, is being performed by Bioremediation Services Incorporated. This portion of the project included the preparation of three trial tests to determine optimization of amendment mixture, equipment and operating procedures; full-scale production composting; demobilization; and site restoration. Details of the project, by Phase, are provided in Chapter 3. Events are presented in chronological order to establish a reference to time of year and length of activity.

3.0 Remediation Process

3.1 Phase I

Analytical results from composite borehole samples taken around the lagoons were used to estimate an approximate volume of 6,339 cubic yards (cy) of contaminated soil. A Contaminated Soil Storage Building (CSSB) was built to accommodate this soil volume for storage and subsequent treatment in Phase II. Post excavation survey of the lagoons revealed thin seams of soil contamination extending beyond the initially excavated area. The Phase I contractor, Wilder Construction Company (WCC), then excavated the additional soil, which was placed in the remaining areas (designated for later use as the treatment area) of the CSSB and on an adjacent asphalt pad, with a reinforced polyethylene liner for cover. The total volume of soil excavated by WCC was 13,245 cy (10,845 cy of contaminated soil plus 2,400 cy of clean soil), an increase of 50 percent over the estimated volume. This increase in volume triggered a chain of events that significantly affected the cost of the remediation and is discussed in subsequent sections as well as in the summary of costs in Chapter 4.

3.1.1 Planning and Contracting

After extensive planning, design, and contract preparation on the part of the USACE, the IFB for Phase I was released, and WCC successfully responded. Initial activity under the contract included the preparation and submission of a number of preconstruction submittals and implementation plans. After receiving a Notice to Proceed (NTP) on November 24, 1993, WCC prepared and submitted the Remedial Action Management Plan (RAMP), which consisted of the following components: Work Plan; Site Safety and Health Plan (SSHP); Contractor Quality Control Management Plan; Environmental Protection Plan; Spill Prevention Plan; Control and Countermeasures Plan; Security and Access Control Plan; Hazard Analysis; WCC Safety Program and Field Supervisor's Safety and Health Manual; Letters of Authorization and Appointment; Resumes and Certifications; Equipment Specifications; and Construction Layout Plans.

3.1.2 Site Setup

As the RAMP was undergoing review, the demarcation of the work zones, as provided in the SSHP, took place. These controlled zones included an Exclusion Zone (EZ), where contamination does or could occur; a Contamination Reduction Zone (CRZ), where decontamination will occur; and a Support Zone (SZ), which is a clean zone outside the CRZ. Only after being clearly delineated with colored tapes, fences, rope, and other barricades could site work commence.

After establishment of the controlled zones on March 14, 1994, the mobilization of construction equipment, facilities, and personnel took place in preparation for site setup work. Initial activities onsite included the clearing and grubbing of work areas, construction/upgrade of roads and decontamination pads to include sumps for wastewater collection/reuse during composting,

establishment of temporary support facilities, hookup of temporary utilities, and construction of an asphalt pad for use in and around the storage building. An existing pad at the site, which was intended to be used, had to be replaced because its slope was too steep. This pad replacement necessitated a contract modification.

With concrete footings in place and foundation ready, assembly of a 200-foot by 90-foot prefabricated metal building known as the CSSB was completed on June 16, 1994 (Figure 3-1). This building was designed to accommodate storage of the initial estimated volume of approximately 6,400 cy of soil and subsequent processing activities. The CSSB prevented runoff and wind erosion of the contaminated soil in Phase I and was intended to accommodate composting operations during Phase II. Immediately adjacent to the CSSB, additional pad space was dedicated to the Material Process Area (MPA), where material stockpiling, processing, and drum handling would occur. In addition, ecology blocks (interlocking concrete blocks used to form retaining or barrier walls) were placed around the inside perimeter of the building (Figure 3-1) to contain and separate contaminated soil stockpiles. The SSHP required air monitoring (Figure 3-2) and dust and vapor control systems in the CSSB to ensure minimum air quality and safe working conditions. To provide ventilation and adequate air flow, 16 louvered exhaust fans were also installed in the CSSB (Figure 3-3).

Figure 3-1. Empty CSSB, UMDA

Figure 3-2. Treatment Building Real-Time Air Quality Monitoring, UMDA
MSA Model 260—Combination methane and oxygen monitoring station equipped with audio and visual alarms to notify personnel in the event preset safety levels are exceeded.

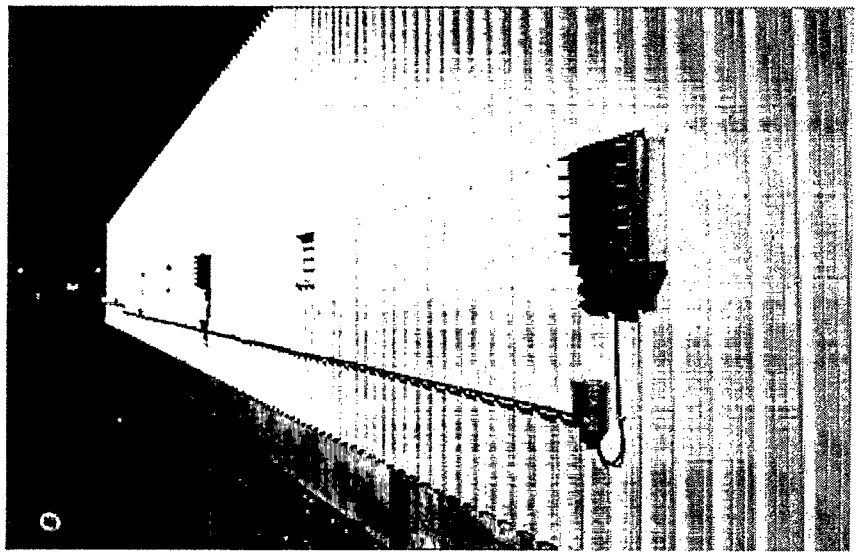

Figure 3-3. Powered Ventilation Fans, UMDA

Immediately after the CSSB was completed, WCC also decontaminated and removed the steel overflow trough, which allowed the spent rinsewater from the explosives washout plant (Bldg. 489 in Figure 2-3) to flow into the lagoons. The inlet and outlet ends of the concrete sump (refer to Figure 2-3), located at the base of the stationary portion of the trough, were sealed with non-shrink grout.

3.1.3 Excavation and Transport

With the soil storage building completed, work focused on the excavation of the contaminated soil from the lagoons (Figure 3-4), which continued from June 21 to July 11, 1994. The contaminated soil was transported via dump truck through a decontamination pad (concrete staging pad sloped to a sump for the collection of all contaminated runoff liquid upon pressure washing of vehicle undercarriage and wheels) to the MPA above the lagoons adjacent to the CSSB. WCC unloaded and screened the soil to remove rocks and debris in preparation for storage in the CSSB. Any non-contaminated soil that was excavated was stockpiled adjacent to the lagoons. Contamination of soil was verified by onsite analysis using EPA Method 8515 for TNT and Method 8510 for RDX. Personnel and perimeter air monitoring was performed during excavation and screening to ensure that airborne concentrations were below the maximum safe limits of 0.25 mg/m^3 for TNT and 2.5 mg/m^3 for respirable dust (Figure 3-5).

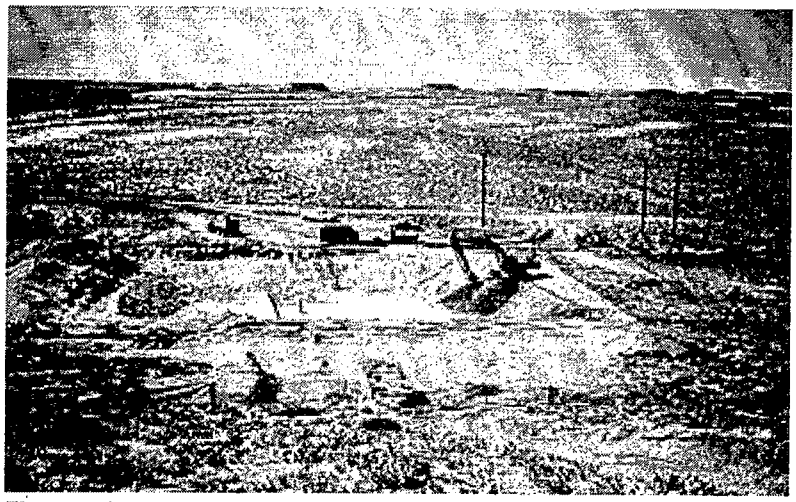

Figure 3-4. Lagoon Excavation, UMDA

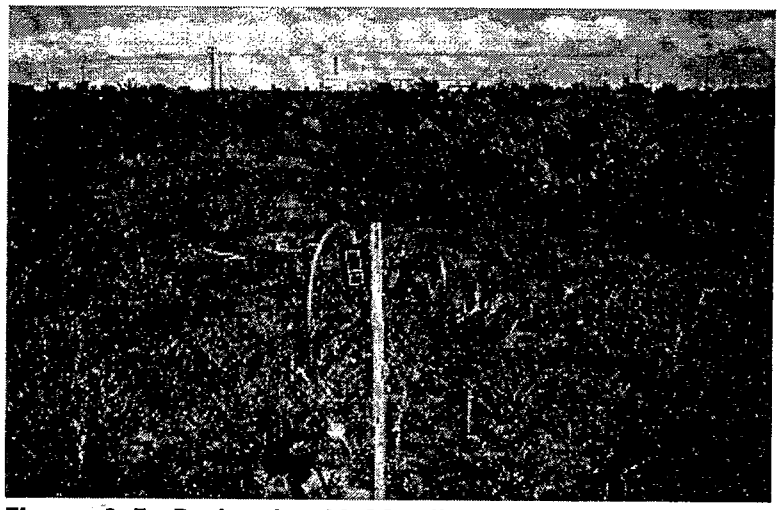

Figure 3-5. Perimeter Air Monitoring, UMDA

Portable upwind/downwind integrated air sampler used to monitor respirable dust and airborne concentrations of TNT and RDX.

On July 11, 1994, WCC suspended excavation work because they were nearing maximum contract soil volume. This suspension occurred despite the appearance of a telltale reddish lens at the sides of the excavated area of both lagoons, indicating the residual presence of TNT. Efforts were temporarily redirected to the removal of storage drums from Buildings 411, 412, and 413 per contract modification. The storage drums were left over from previous RI/FS work at the site and contained either soil, water, or clothing. The drums containing soil were transported to the material handling area and screened in the same manner as the excavated soil; the drums containing water were set aside for inclusion in Phase II composting; and the drums containing clothing were shipped offsite for disposal.

WCC resumed excavation on July 25, 1994 after receiving a contract modification to excavate the additional volume of contaminated soil that did not achieve the <30 ppm cleanup level for TNT and RDX. Excavation under this contract modification was completed on August 1, 1994, with an additional day of soil screening required to screen the backlog of stockpiled soil. The contract modification also addressed the disposition of the soil contained in the drums. After sampling analysis for TNT or RDX indicated no levels >30 ppm, they were sealed and returned to Bldg. 412 pending decision on final disposition.

As reddish lenses of TNT-contaminated soil were still observed in the excavated lagoons, WCC returned, once again, to continue excavation of three stratified layers of contaminated soil in the four sidewalls of both lagoons. The three contaminated layers of soil were separated by non-contaminated soil. Excavation of both contaminated and non-contaminated soil from the sidewalls of the lagoons totaled 3,300 cubic yards. Another contract modification ($147,000) addressing the additional excavation, screening, sampling and analysis, and stockpiling was prepared to accommodate the total 10,845 cy of contaminated soil actually excavated.

Due to this unforeseen increase in soil volume, WCC was directed by USACE to store the excess contaminated soil outside the CSSB on the asphalt pad because the CSSB, which was designed and built to accommodate the original estimate of 6,339 cy, was at capacity prior to completion of soil excavation. Ecology blocks were used for containment and a reinforced 18-mil polyethylene liner was secured with sandbags for cover. This final excavation was completed on September 6, 1994.

3.1.4 Chemical Analysis

In accordance with the Contractor Quality Control Management Plan, rigorous onsite analyses for TNT and RDX within pre-established grids were performed using EPA Method 8515 for TNT and Method 8510 for RDX to guide excavation depths and widths where the cleanup level of <30 ppm had not yet been attained. Furthermore, composite samples were regularly taken, prepared, and shipped offsite to a chemical laboratory for confirmatory analysis using EPA Method 8330.

After the final excavation of the stratified layers, onsite analysis and confirmatory analysis of 40 discrete samples taken from 8 grids in the bottom of the lagoons indicated that cleanup criteria had been met for TNT but not for RDX. Further review of the analytical data by USACE

indicated that the sampling and analytical process protocols had not been properly followed, prompting an additional 40 samples to be obtained and analyzed. This additional work triggered yet another contract modification and an extension of approximately 4 weeks to accommodate laboratory analysis. While the second sample batch was being analyzed (and ultimately accepted), WCC effected temporary closure of the lagoons by laying in approximately 2 feet of gravel and performing a final grading of the excavated area.

3.1.5 Decontamination, Demobilization, and Site Restoration

Decontamination, demobilization, and site restoration of Phase I activities began after excavation was completed. All equipment was decontaminated and inspected; utilities were cut off and removed; and all temporary and supporting facilities were either properly disposed of and/or removed from the site. Phase I closeout occurred on September 20, 1994. A timeline of Phase I activities is provided below in Table 3-1.

Table 3-1. Phase I—Timeline

Activity	Start Date	Finish Date
Notice to proceed	November 24, 1993	—
Site Setup	March 14, 1994	June 16, 1994
Excavation and Transport	June 21, 1994	September 6,1994
Chemical Analysis	June 21, 1994	September 14, 1994
Decontamination, Demobilization, and Site Restoration	September 14, 1994	September 20, 1994

3.2 Phase II

As mentioned in Section 2.3, some duplication of effort was inevitable because of the use of two contracts. Much of this duplication was evident in Phase II, beginning with the contract preparation on behalf of the USACE followed by Bioremediation Services Incorporated's (BSI) preparation of the first of two RAMPs for Phase II and the subsequent remobilization of the site. A second RAMP was required in Phase II to incorporate the results of the trial tests as well as the comments regarding RAMP I. Furthermore, the chain of events and added costs associated with the increased soil volume in Phase I were also apparent in Phase II.

3.2.1 Planning and Contracting

The contract for Phase II of the remediation effort was awarded to BSI upon completion of a protracted selection, evaluation, and award process. After receiving a NTP on June 13, 1994, BSI prepared the first RAMP containing the following subdocuments: Composting Treatment Trial Test Plan; Site Safety and Health Plan (SSHP); Contractor Quality Control Management Plan; Environmental Protection Plan; Ventilation Plan; Network Analysis Plan (Integrated Project Activity Duration Spreadsheet); and Temporary Treatment Building Plan. USACE issued approval of the Final RAMP I on November 18, 1994.

3.2.2 Site Setup

As BSI reestablished work zones per the SSHP, they also mobilized construction equipment, facilities, and personnel in preparation for site setup work. Initial site activity began on December 19, 1994, and included the following: grubbing and clearing of work areas, construction of roads and decontamination facilities, establishment of a field office, installation of an onsite laboratory, hookup of temporary utilities, and preparation of a baseline air monitoring survey.

The existence of the additional volume of excavated contaminated soil prompted USACE to exercise one of its contract options to lease temporary building storage space from BSI for the soil. BSI provided the space in the form of three tents (owned by BSI) erected adjacent to the CSSB. The tents provided for storage of all contaminated soils so that the CSSB could be emptied and used solely as the treatment facility. All soil, except the first batch of soil intended for treatment, would be moved from the CSSB and the adjacent asphalt pad into the BSI tents to provide adequate ventilated space for BSI's turning equipment in the treatment building.

The BSI tents were leased to USACE with a contract modification of $487,000, which includes the costs for a 2-year lease on the BSI tents, site setup of the tents, and demobilization of the tents. Site setup for the tents included clearing, grubbing, and grading in preparation for an asphalt pad on which the tents were placed. The tents provided 42,250 square feet of soil storage space to accommodate the storage of all excavated soil stored in the CSSB and on the nearby asphalt pad. The tents were delivered to the site on January 30, 1995, and were erected by February 9, 1995. The movement of all contaminated soil (including the soil stored in the CSSB and the soil stockpiled on the adjacent asphalt pad) into the tents was delayed because one of BSI's subcontractors was unable to ensure all employees had proper hazmat certifications. After this was rectified, the soil transfer process began on March 7, 1995, and concluded the following day in preparation for the trial tests (Figure 3-6).

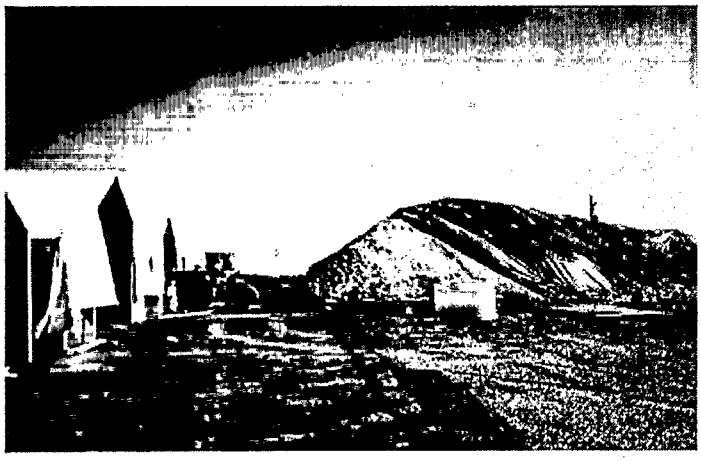

Figure 3-6. Contaminated Soil Being Moved into Storage Tents, UMDA

3.2.3 Trial Tests

Prior to full-scale composting, three small trial test windrows were constructed in the CSSB. BSI conducted the trial tests to: (1) determine the timeliness and effectiveness of composting at reducing TNT and RDX concentrations; (2) correlate field data (using EPA Method 8515 for TNT and Method 8510 for RDX) and laboratory data (using EPA Method 8330) of the test windrows; (3) plan alternative actions, if necessary, to improve degradation rates if action levels of 30 ppm for TNT and RDX were not achieved within 40 days; and (4) determine the optimum turning frequency for full-scale operations. BSI monitored a number of physical characteristics during the trial tests including temperature, pH, moisture level, and gas/vapor production. These physical tests helped BSI determine optimum pile turning frequency.

During the trial test, BSI employed an intense regimen of sampling and analysis, using EPA Method 8515 for TNT and Method 8510 for RDX for onsite analysis and Method 8330 for laboratory confirmational analysis. The increased number and frequency in sampling was performed to determine TNT and RDX concentrations at specific sampling locations and time intervals within the three windrowed compost piles. Three test piles were prepared, in part, to accommodate three different turning strategies. The loading ratio of contaminated soil (30%) to amendments (70%) were the same for all three test piles (see below). The turning frequencies for the first two windrows were 24- and 72-hours, while the third windrow underwent a varied turning cycle: every 24 hours for the first 10 days, every 72 hours for the next 10 days, and at 168 hours for the final 10 days. Samples were taken and analyzed from all of the windrows at the start of the test period and then at 5-day intervals for 30 days until the average concentrations of TNT and RDX were determined to be statistically below 30 ppm. The optimum turning frequency was the varied turning cycle, with frequent turning during the first 3 to 5 days followed by less frequent turning. Frequent turning of the windrows improves the biodegradation process and is most effective over the initial 3 to 5 days when the decomposition rate is greatest. As the process continues, the biodegradation process is not affected by a reduction in the turning frequency.

The trial tests, consisting of 120 cy of contaminated soil (each windrow containing 40 cy of contaminated soil), were conducted using 30 percent soil by volume, with the remaining 70 percent composed of amendments. BSI blended the amendments at approximately a 1:3:5.4:5.4:6.5 ratio of chicken manure:potato waste:alfalfa:sawdust:cow manure. BSI used the same soil loading rate and the same amendments at the same ratio used in a previous preliminary treatability study performed at UMDA.

The trial tests began on March 20, 1995, after all necessary equipment had been checked and calibrated and adequate amendments had been bought, delivered, and properly blended (specific procedures and equipment used in the composting process employed at UMDA are discussed in Section 3.2.4). By April 10, 1995, (11 days after initiation of composting) onsite analysis of the trial windrows by EPA Method 8515 for TNT and Method 8510 for RDX indicated that virtually all contaminants were at nondetectable levels. BSI took confirmatory samples to verify cleanup levels via EPA Method 8330 on April 13, 1995. The trial tests were completed on April 19, 1995.

As required by the contract, BSI prepared and delivered the second RAMP (RAMP II) which incorporated the results of the trial tests as well as comments regarding RAMP I on April 24, 1995. Draft RAMP II included a Production Composting Treatment Plan and Revegetation Plan to effect contract closeout. After USACE review and comment, a final RAMP II was prepared, submitted, and approved on July 3, 1995, clearing the way for full-scale production composting to begin.

3.2.4 Full-Scale Composting

While the trial test confirmed the prescribed amendment mixture, soil loading rate, moisture content (30 to 35 percent) by weight, and turning frequency (every 24 hours the first 5 days followed by less frequent turning on subsequent days), it also revealed that the originally scheduled processing time could be significantly reduced from 40 days to approximately 22 days (8 to 10 days of which were spent waiting for offsite laboratory confirmatory analysis). BSI calculated the total contaminated soil to be 10,969 cy (as opposed to WCC's estimated volume of 10,845 cy). BSI, therefore, planned to construct 13 windrow batches, each containing 810 cy of soil (10,530 cy) and 1 batch containing 439 cy. These volumes were calculated based on the operational constraints of the apparatus that was used to turn windrows during the trial tests, which were conducted within the 200-foot by 90-foot CSSB. Because Phase I work started prior to the contract award of Phase II, there was no interface between the Phase I and Phase II contractors. Consequently, the CSSB was not designed to accommodate the turning radius of BSI's specialized turning machine (the "Wendy"). BSI began full-scale production composting on July 18, 1995.

The Process Flow Diagram shown in Figure 3-7 depicts the entire process used for all 14 batches, beginning with preparatory soil screening in the upper left corner. BSI determined that screening conducted during Phase I was inadequate for composting. All contaminated soil was rescreened to remove large chunks of construction debris and rocks (Figures 3-8 and 3-9).

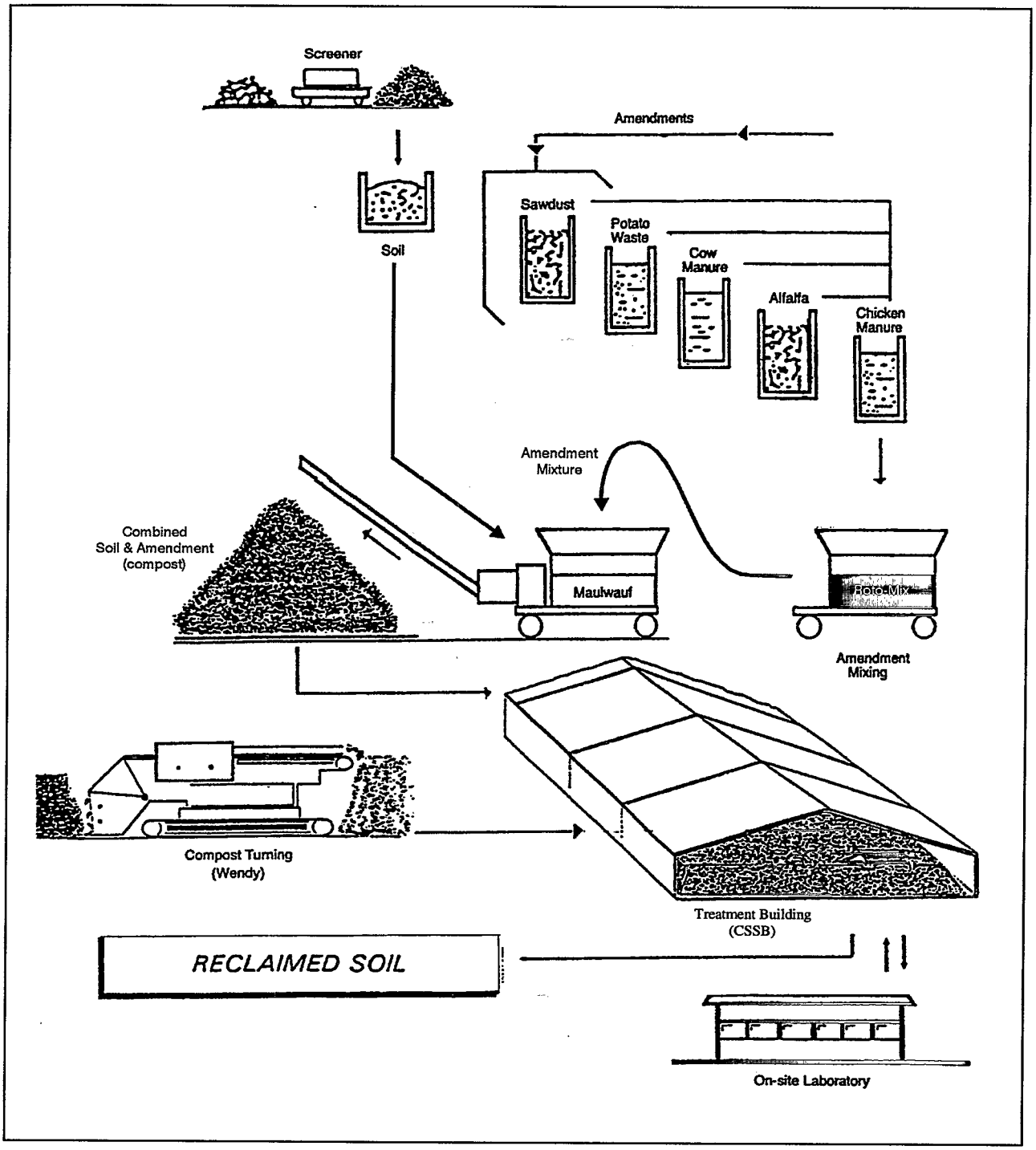

Figure 3-7. Process Flow Diagram, UMDA

Source: (2)

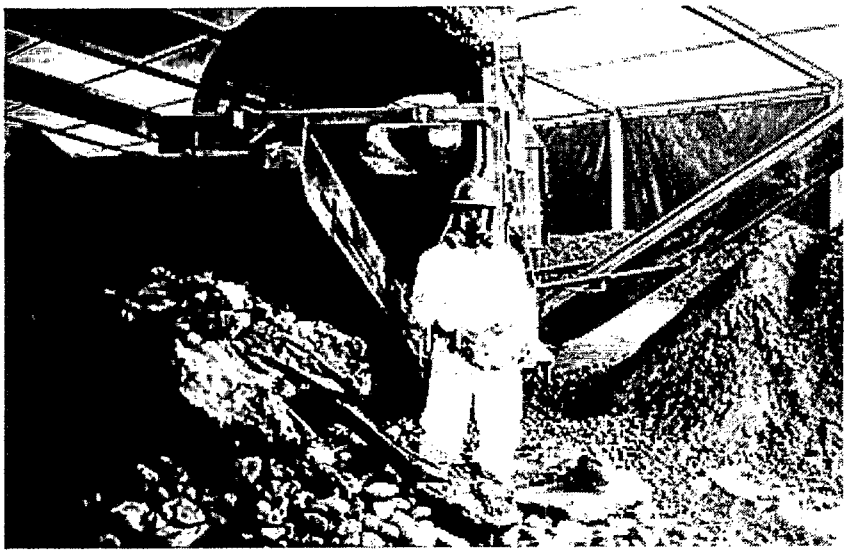

Figure 3-8. Screening Oversized Rocks and Concrete, UMDA

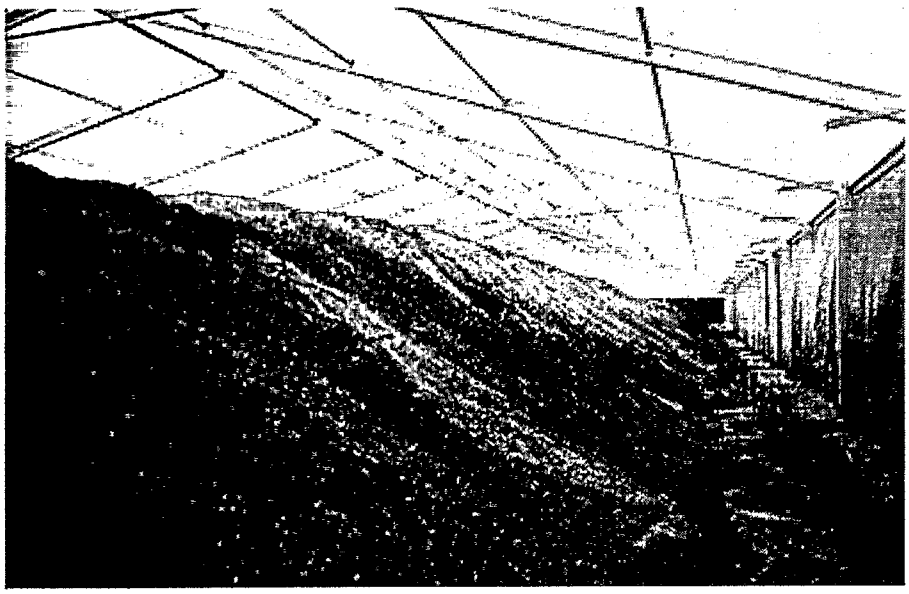

Figure 3-9. Screened Soil Inside Storage Building, UMDA

With amendments procured and stored (Figures 3-10 and 3-11), mixing of the prescribed blend was initiated with retrieval of the selected amendment from the appropriate bin (Figure 3-12). The amendments were always premixed before they were mixed with the contaminated soil. This two step process encouraged early initiation of microbial activity. The mixing of amendments was performed using the front-end loader/Roto-Mix system. Amendments were loaded into the Roto-Mix hopper which was mounted on four load cells connected to a digital scale allowing precise and rapid batching of each amendment. BSI established a correlation between weight of amendments and required volumes. Once loaded, the Roto-Mix combined the

three actions of folding, cutting, and shearing to ensure thorough amendment homogenization (Figure 3-13).

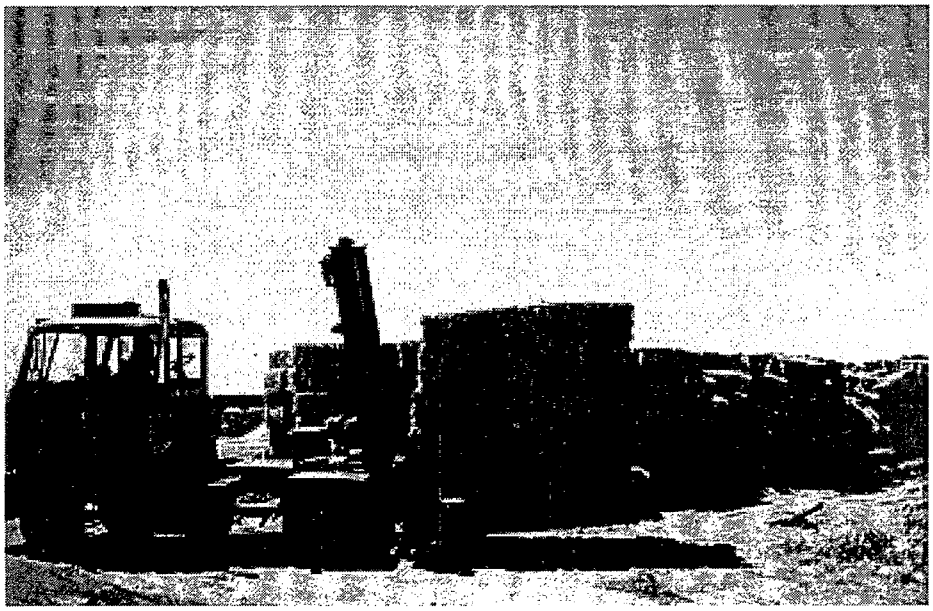

Figure 3-10. Vendor Delivering Alfalfa, UMDA

Figure 3-11. Stored Amendments Separated by Ecology Blocks, UMDA

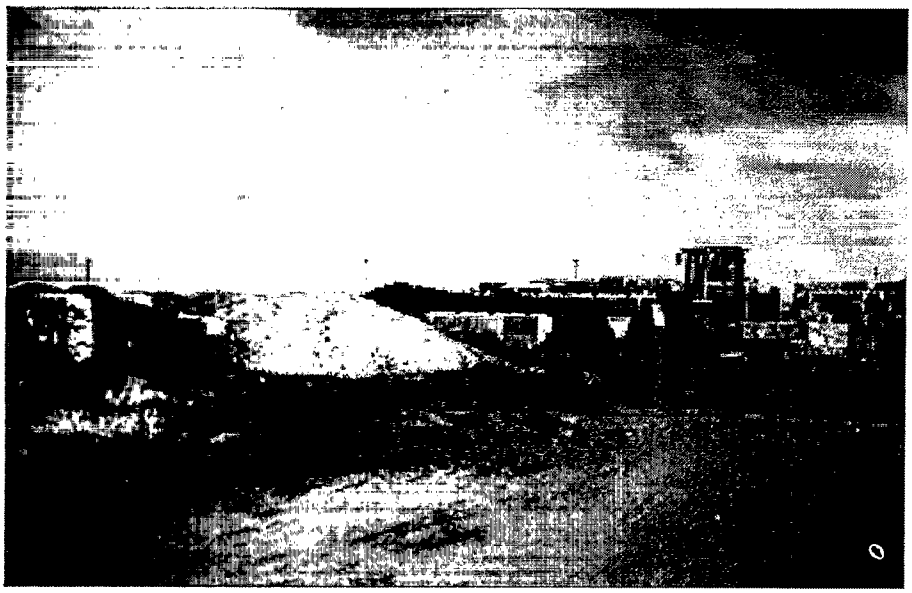

Figure 3-12. Pulling Amendments for Mixing, UMDA

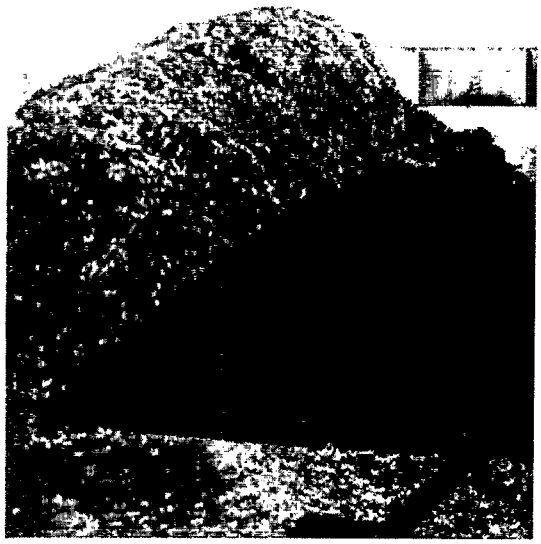

Figure 3-13. Mixed Amendments, UMDA

The mixed amendments were then loaded into a "maulwauf" soil mixing unit located on the Materials Processing Area (MPA) (Figure 3-14) with the front-end loader. Screened contaminated soil was also loaded into a soil hopper driven by the maulwauf. The maulwauf

conveyed the amendment mixture to a shredder chamber, where it was mixed with contaminated soil in a 7:3 volumetric ratio. The compost was then carried by belt conveyor and discharged onto the MPA for loading into the CSSB for treatment. Using a front-end loader, the material was arranged into a windrow measuring 165 feet by 55 feet by 7 feet.

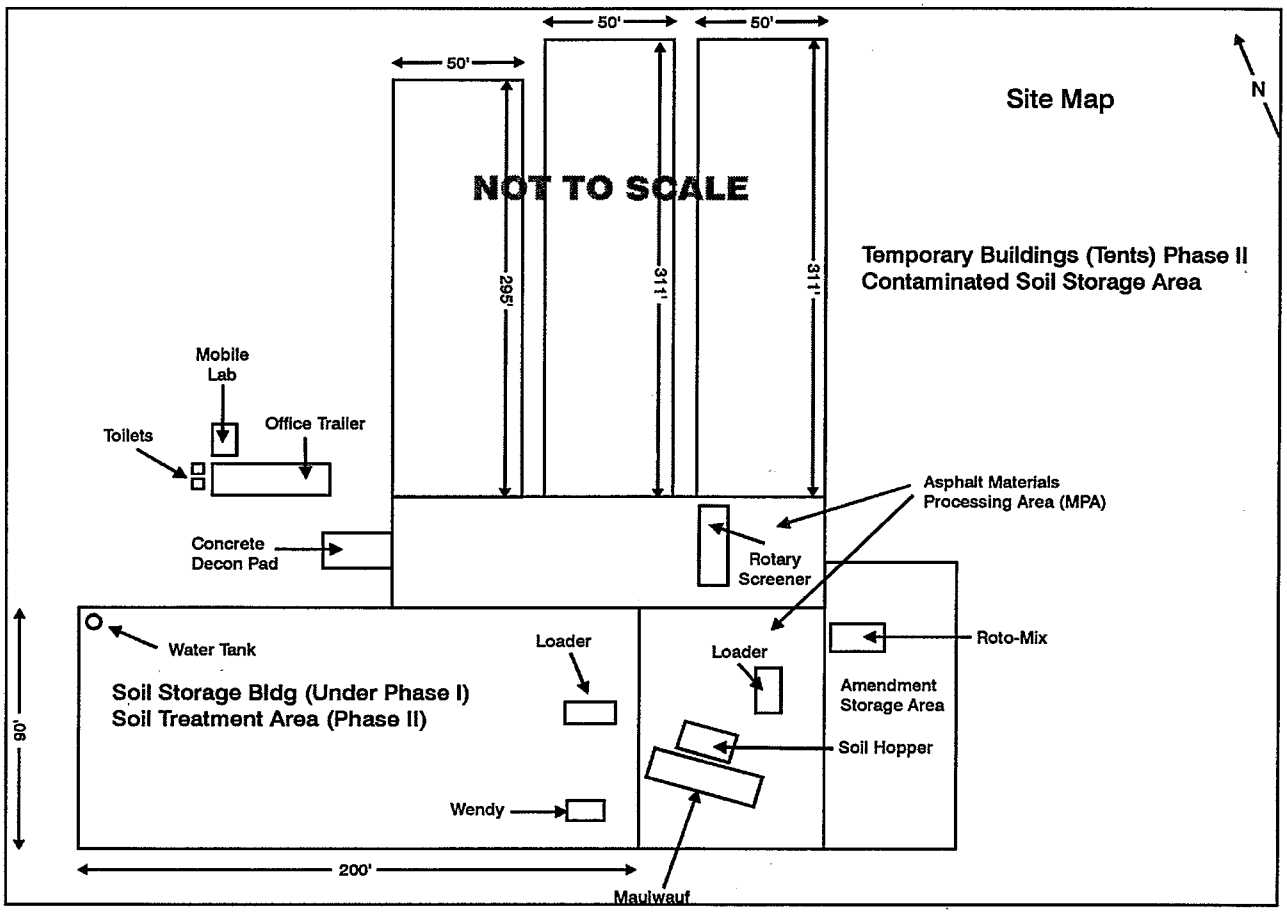

Figure 3-14. Site Map, UMDA

To ensure compost homogenization, oxygenation, and sufficient contact between microorganisms and contaminants, the windrows were turned every 24 hours for the first 5 days of treatment then less frequently on the following days. BSI used a compost turning machine, called the "Wendy" (Figure 3-15) to turn the windrows. The process of turning introduced oxygen and removed heat. Although the compost turning machine leaves the windrow largely intact upon turning, any necessary reshaping was done by a front-end loader.

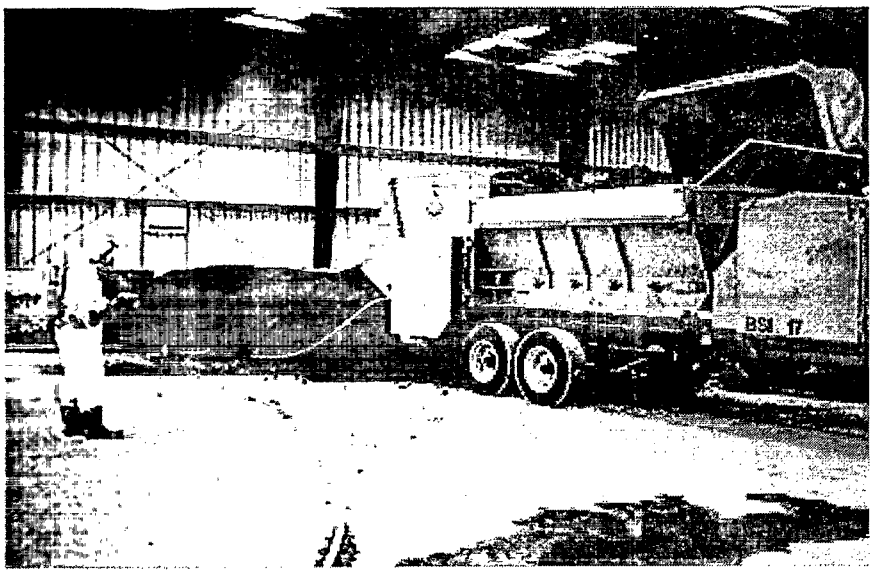

Figure 3-15. Turning of a Windrow, UMDA

3.2.5 Chemical Analysis

During the course of the composting operation, monitoring of the material for temperature, percent oxygen, percent moisture, pH, and explosives concentration was performed regularly. Temperature was monitored intermittently via probes placed in and along the length of the pile. Oxygen, which had been determined from previous studies to drop to an equilibrium level rapidly after turning, was monitored daily using a hand-held meter attached to a probe. Percent moisture, as well as pH, were monitored twice a week with moisture being added as needed to maintain optimum conditions.

The remaining contaminant level was determined using EPA Method 4050 for TNT and Method 4051 for RDX during onsite analysis. EPA Method 8330 was used for confirmatory laboratory analysis. Although Methods 8515 and 8510 were effective in determining contaminant levels in explosives-contaminated soil, Methods 4050 and 4051 exhibited better correlation with laboratory analysis data (Method 8330) after nitrogen rich amendments are mixed with the contaminated soil. The colorimetric technique used in Methods 8515 and 8510 experienced interference from the nitrogen rich amendments. In contrast, the immunoassay technique used in Methods 4050 and 4051 takes advantage of the ability of antibodies to selectively bind to specific target compounds present at low concentrations in the sample matrix. This change in onsite analysis was approved by USACE on June 26, 1995, so subsequent onsite analyses were conducted using Method 4050 for TNT and Method 4051 for RDX, while Method 8330 was still used for confirmatory laboratory analysis. In accordance with the Phase II Contractor Quality Control Management Plan, onsite analyses for TNT and RDX were conducted after the soil had been initially mixed with the amendments and periodically thereafter until the cleanup goal of <30 ppm was met. Average concentrations of contaminant taken from archived compost samples collected from day 0 during trial test composting were 190 ppm for TNT and 227 ppm for RDX. Once the cleanup level was attained, as indicated by onsite analysis (Figure 3-16), confirmational

sampling was conducted. Two discrete random grid samples (Figure 3-17) representing a maximum of 30 cy of contaminated soil (grid size) were taken from each grid and sent to an offsite chemical laboratory for confirmatory analysis using EPA Method 8330.

Figure 3-16. Onsite Analysis (TNT/RDX), UMDA
Using test protocols based on Methods 8515 (TNT), and 8510 (RDX).

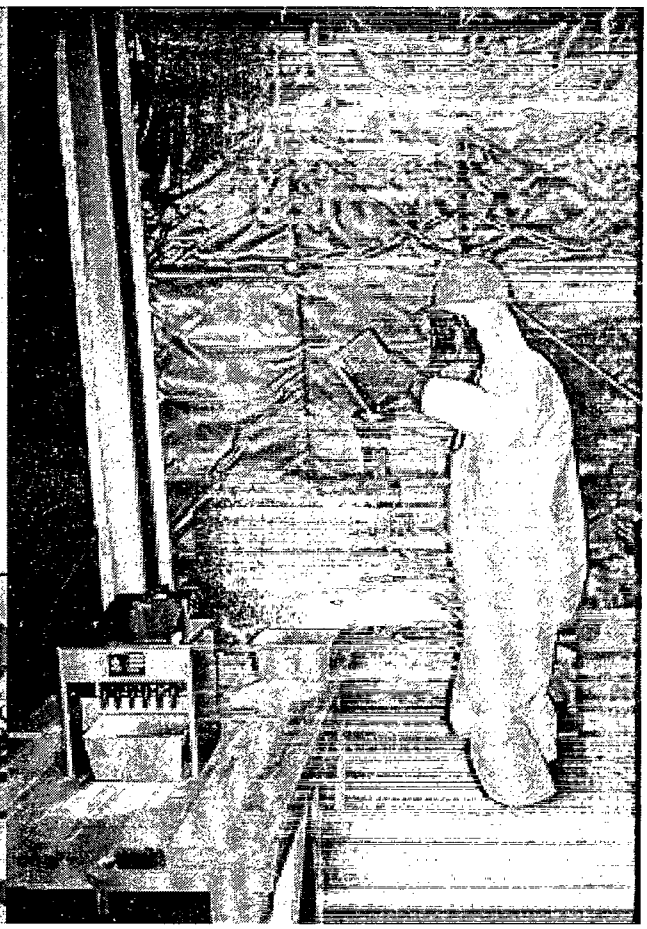

Figure 3-17. Split Sample Preparation, UMDA
Preparation as required by QA/QC plan for offsite confirmatory analysis using Method 8330.

A grid is equivalent to 30 cubic yards of contaminated soil, so a batch containing 810 cubic yards of contaminated soil would have 27 grids. Two random samples are taken from each grid over the whole windrow for a total of 54 samples. If only one or two grids fail the <30 ppm cleanup level, then only those grids are re-sampled. If more than two grids fail, then additional treatment is resumed to facilitate further degradation before additional sampling occurs.

BSI experienced only two failed grids on separate windrows during treatment. In Batch 3, a grid sample showed mean concentrations of both TNT and RDX at 33.5 ppm. A second sampling indicated that TNT and RDX were below 30 ppm, suggesting that the first sample contained an explosive speck. A second instance of a failed grid occurred in Batch 11 (see Figure 3-18), with concentrations of 46.5 ppm for TNT and 61 ppm for RDX. The other 26 grids in Batch 11 were below the 30 ppm action level. The failed grid was segregated from the other batches and

incorporated into a subsequent batch for further treatment. Once laboratory analysis confirmed that both TNT and RDX were below 30 ppm, the composting batch was transferred out of the CSSB (Figure 3-19) and stockpiled under cover (Figure 3-20) for eventual return to the excavated area.

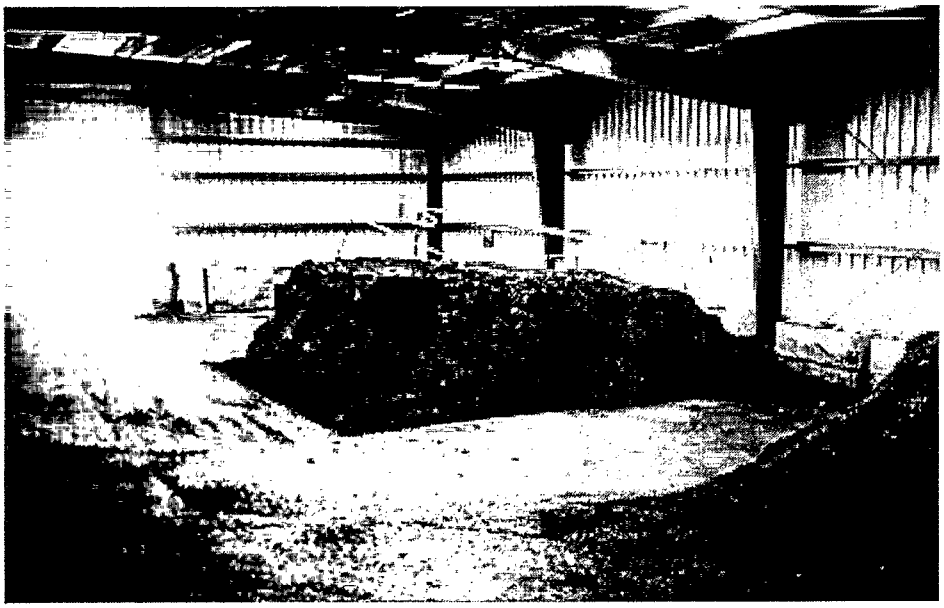

Figure 3-18. Segregated Failed Grid Batch, UMDA

Figure 3-19. Loading Treated Soil, UMDA

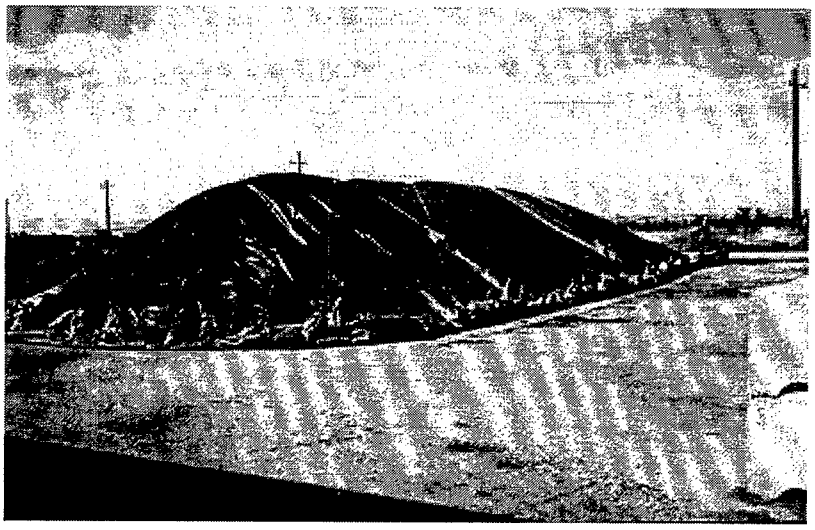

Figure 3-20. Temporary Treated Soil Stockpile, UMDA

Batch 1 was completed on August 23, 1995, 23 days after windrow construction. Similar processing times for the remaining batches have been recorded. Project completion has been revised to occur on or around September 1, 1996, approximately one year ahead of the original project schedule.

3.2.6 Demobilization/Site Restoration

Once a composting batch is completed, the treated soil is transferred by dump truck to a final stockpile area adjacent to the lagoons. The USACE will transfer the soil back into the lagoons after a separate groundwater remediation effort is complete. Because the volume of material will have increased by approximately 75 percent due to the addition of the amendments, a mounding effect will occur. This mound is anticipated to be capped with a foot or two of common borrow, graded, and seeded with rye or other suitable vegetative cover. Additional closeout activities will include the decontamination and demobilization of all equipment, disconnection of utility hookups and services, and recycling of all asphalt materials. Any waste will be removed from the site and use areas will be restored. BSI's submission of a closeout report is anticipated on or about September 1, 1996. Table 3-2 shows the timeline of Phase II activities.

Table 3-2. Phase II—Timeline

Activity	Start Date	End Date
Notice to proceed	June 13, 1994	—
Site Setup	December 19, 1994	February 9, 1995
Trial Tests	March 20, 1995	April 19, 1995
Full-scale Composting	July 18, 1995	September 1996*
Chemical Analysis	March 20, 1995	September 1996
Demobilization/Site Restoration	September 1996*	December 1996*
*Anticipated		

4.0 Summary of Costs

4.1 Remedial Action—Work Breakdown Structure (RA-WBS) Methodology Overview

All cost data collected for this report have been organized according to the format specified by the Remedial Action-Work Breakdown Structure (RA-WBS). This cost methodology provides a common language that can be used to ensure clear communications among those who work on a project, including accountants, supervisors, foreman, engineers, regulatory officials, and legal professionals. The Interagency Cost Estimating Group (ICEG) developed this method of cost reporting for tracking full-scale remediation projects because it facilitates widespread use and comparability across agencies and various media. The ICEG is composed of cost and project management professionals with a broad spectrum of experience in environmental restoration. Those professionals represent the U.S. Environmental Protection Agency, the U.S. Department of Energy, the U.S. Army Corps of Engineers, the Naval Facilities Engineering Command, and the U.S. Air Force. The group has been augmented at times by individuals from the private sector and other Federal agencies.

The standard RA-WBS contains a comprehensive list of predefined cost elements (tasks, items, or products) that have been identified through experience as required to accomplish a typical project. The list can be arranged in spreadsheet format and defines each cost element, including its unit of measure, and assigns each element a unique number composed of up to five sets of two-digit numbers. The spreadsheet organizes the elements such that related items are grouped together to form a hierarchy. The lower the level on the hierarchy, the more detailed the items become. The RA-WBS hierarchy has five levels of detail. Level 1 defines the project as a hazardous, toxic, and radioactive waste (HTRW) remedial action project. Level 2 lists major work categories generally found in a remediation construction project. At Level 3, items that are used to accomplish Level 2 categories appear, while Levels 4 and 5 represent further detail of cost items associated with the project. Table 4-1 provides an example of a completed RA-WBS for a fictional project.

Table 4-1. Work Breakdown Structure Reporting Example

PROJECT COSTS (X $1,000)						
		COST	COST	COST	UNITS	UNIT COST
33.01	MOBILIZATION AND PREPARATORY WORK	$ 48				
33.01.02	Mobilization of Personnel		$ 48			
33.01.02.01	Relocation of Personnel			$ 48	4	12/EA
33.03	SITE WORK	$ 400				
33.03.04	Roads/Parking/Curbs/Walks		$ 100			
33.03.04.04	Concrete Surfacing			$ 50	100	0.5/CY
33.03.04.10	Signs			$ 11	22	0.5/EA
33.03.04.90	Sewage Vents			$ 39	3	13/EA
33.03.05	Fencing		$ 50			
33.03.05.01	Fencing			$ 45	4500	0.01/LF
33.03.05.02	Gates			$ 5	100	0.05/LF
33.03.10	Fuel Line Distribution		$ 250			
33.03.10.01	Fuel Line Distribution			$ 200	20000	0.01/LF
33.03.10.03	Connections/Fees			$ 20	50	0.4/EA
33.03.10.30	Tests			$ 30	5	6.0/EA
33.05	SURFACE WATER COLLECTION AND CONTROL	$ 50				

An important feature of the RA-WBS is the ability to add additional cost categories where needed to customize the cost reporting. These cost elements are added by the user into "blank" areas located throughout the structure. For example, preparation of a RAMP did not appear as a line item in the existing RA-WBS structure and was added in the appropriate location under Element Number 33.01—Mobilization and Preparatory Work. Because windrow composting of explosives-contaminated soils is considered an innovative technology, several cost elements were not included in the existing structure. Instead, they were added in appropriate locations using the "nonstandard element" notation indicated by the number 9x, where x was replaced with a digit corresponding to the number of item(s) added. Separate WBS spreadsheets were prepared for Phase I and Phase II.

4.2 Assumptions and Limitations/Level of Documentation

Cost data used in this report came exclusively from the original contract, contractors' requests for payment, and the corresponding payment records prepared by USACE. Contract files were accessed to determine original contract pricing as well as financially significant modifications to the contracts. The format in which the contractors provided cost data was not readily converted for inclusion into the RA-WBS and as a result, caused some difficulty. Future data collection could be facilitated if remedial action contractors reported cost in the RA-WBS or similar format.

As this project was funded via government appropriations on a fiscal year basis, no debt service or carrying cost is included. Because projects conducted at other government installations may also be subject to the Resource Conservation and Recovery Act (RCRA) facility design requirements applied at UMDA, any discussion of potential cost reduction associated with variations of applicable regulation(s) has been foregone. It is important to note, however, that at an EPA Regional Administrator's discretion, the RCRA facility design requirements may be waived.

Additional sources of information for this cost report included the Best and Final Offer (BAFO) solicitation packages submitted on behalf of each contractor, RAMPs submitted under the respective contracts, monthly progress reports, and daily and weekly quality control reports provided by the contractors and onsite USACE representative. To the extent practicable, this report uses actual payment figures.

4.2.1 Fixed Costs vs. Variable Costs

This report identifies the various cost elements as either "fixed" or "variable." As used in this report which applies to the UMDA remediation effort, fixed costs refer to those costs incurred at UMDA that do not vary with the volume of soil treated. Mobilization and Preparatory Work represents a fixed cost because this activity must be done to accomplish the work, and its cost is irrespective of soil volume. That is, mobilization and preparatory work must be done to treat 1 ton or 10,000 tons of soil, and its dollars will remain relatively the same for either volume. This report considers analytical work (Monitoring, Sampling, Testing, and Analysis) as a variable cost since the total dollars associated with this cost element is directly related to the volume of soil; that is, more soil increases the number of tests, and inherently the total dollars. The sum of all of the fixed costs represents the minimum cost for operations at UMDA. Variable costs (e.g., amendments, sampling) are calculated by multiplying the unit variable cost with the number of units (e.g., tons, cubic yards, samples) processed. Total cost for processing soil at UMDA is then the summation of all variable costs and all fixed costs. At UMDA, the unit cost (dollars per ton) for treatment of small soil volumes would be high due to the high up-front fixed costs and low treated soil volume. The unit cost for treating larger soil volumes at UMDA increases marginally at first, then levels off as fixed costs are spread over static unit cost of processing soil.

To estimate the unit cost at other sites, some cost elements identified here as "fixed" for UMDA will change based on site-specific conditions. Therefore, cost elements identified as "fixed" for UMDA will not represent the actual cost at another site. This report identifies Site Work as a fixed cost, because the cost for clearing and grubbing of the area did not change with the volume of soil treated. However the fixed cost for Site Work at UMDA ($526,294, combined cost for Phase I and Phase II) will not be the same for another site unless it has the same vegetation, same soil, same topography, and same surface area as UMDA. A site with considerable vegetation, high slopes, and no existing roads will experience a higher cost for site work than a site that is clear of vegetation, relatively flat, and with existing roads.

The unit variable costs (e.g., cost of each laboratory sample, cost of alfalfa per ton) at UMDA can be translated to other sites with similar conditions. Unit cost for some of the variable cost

elements will also vary at other sites according to factors such as type of contaminants and concentration of contamination, type of amendments used, availability of amendments, cost of amendments, and regional labor rates. These factors will cause the unit variable costs to differ from UMDA even before factoring in the number of units (e.g., soil volume, number of samples).

4.3 Cost Breakdown—Phase I

Each of the eight general work areas appearing in the RA-WBS for Phase I is represented in Table 4-2 below indicating activity, total cost, percentage of Phase I cost, as well as percentage of the combined Phase I and Phase II cost ($5,131,106). Table 4-2 identifies the cost elements as fixed or variable costs. Fixed costs do not vary with project duration or the volume of contaminated soil to remediate, while variable costs change according to site specific variables (e.g., nature and extent of contamination, soil characteristics, climatic conditions) and with the soil volume to remediate (i.e., overall project cost rises with increased volume of soil). Figure 4-1 shows graphically the HTRW level 2 costs.

Table 4-2. Phase I Cost Breakdown

Work Area	Activity	Cost	% of Phase I Cost	% of Phase I and II Cost
33.01	Mobilization and Preparatory Work [1]	$257,000	19.47%	5.01%
33.02	Monitoring, Sampling, Testing, and Analysis [2]	$87,478	6.63%	1.70%
33.03	Site Work [1]	$506,294	38.35%	9.87%
33.08	Solids Collection Containment [2]	$403,578	30.57%	7.87%
33.10	Drums/Tanks/Structures/Misc. Demolition and Removal [2]	$39,812	3.02%	0.78%
33.20	Site Restoration [1]	$21,000	1.59%	0.41%
33.21	Demobilization [1]	$5,000	0.38%	0.10%
PHASE I TOTAL COST		**$1,320,162**		**25.73%**

Notes:

1 Fixed Costs
2 Variable Costs

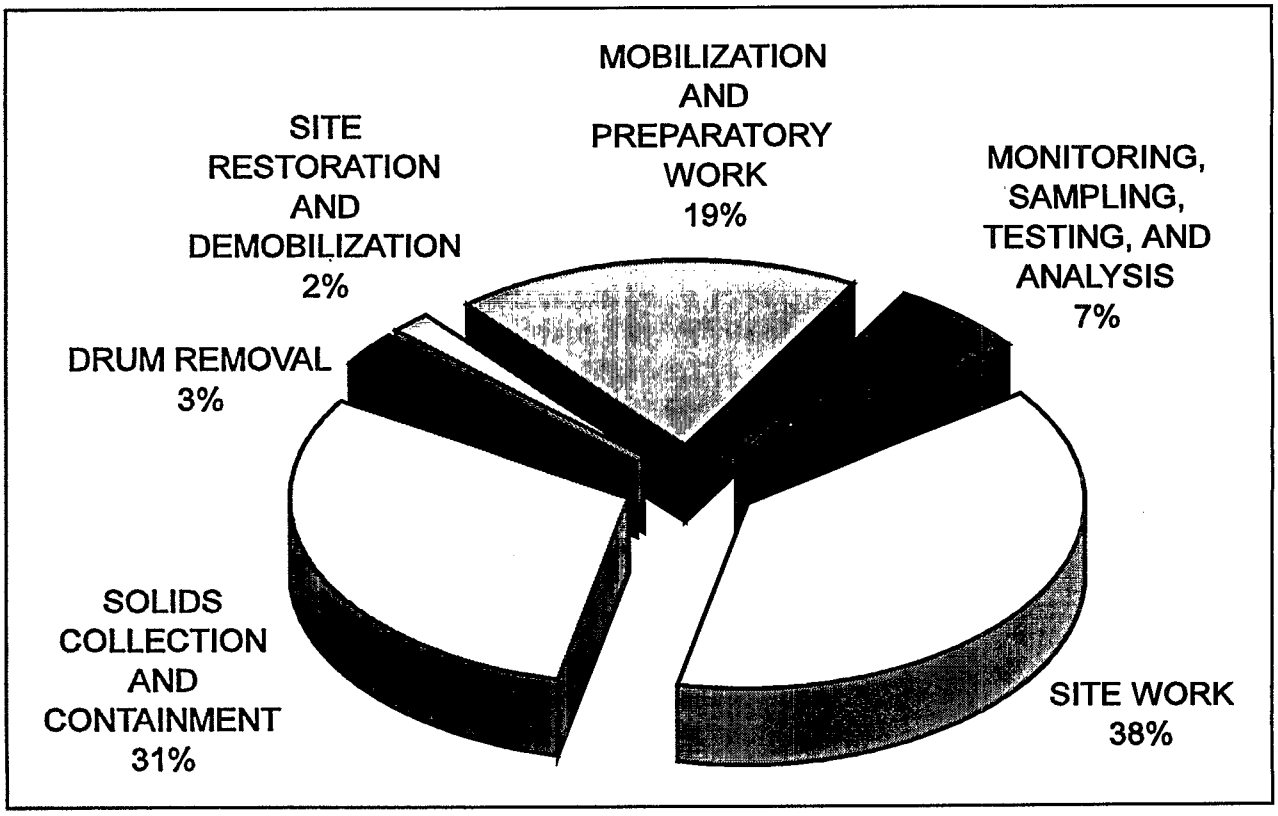

Figure 4-1. Phase I—Total Cost

The four largest areas of cost concentration occurring in Phase I are: Site Work at 38 percent, Solids Collection and Containment at 31 percent, Mobilization and Preparatory Work at 19 percent, and Monitoring, Sampling, Testing, and Analysis at 7 percent. The balance of the general work categories in Phase I comprise approximately 5 percent of the Phase I cost (Drums/Tanks/Structures/Miscellaneous Demolition and Removal at 3 percent, Site Restoration and Demobilization at 2 percent). Drum removal was unique to UMDA and will probably not occur at other sites.

Given that the primary thrusts of Phase I were to construct a storage building, excavate the contaminated soil, and relocate the material to the storage building, the distribution of the costs are consistent with the tasking.

The breakdown of cost provided via record of payment and request for payment histories, did not always lend itself to ready categorization in the RA-WBS format. RA-WBS elements 33.01.01—Mobilization of Construction, Equipment & Facilities and 33.01.02—Mobilization of Personnel had to be included in the subsequent RA-WBS element 33.01.04—Setup/Construct Temporary Facilities due to WCC's practice of grouping these costs together.

Additional considerations in examining costs associated with Phase I activity at UMDA include RA-WBS work area 33.03, Site Work, where the demolition cost associated with the removal of

the asphalt pad appears. Depending on the facility, existing pad sites may be present and should be included in the site selection evaluation to avoid or reduce demolition cost. RA-WBS category element 33.03.02, Clearing and Grubbing, was not applicable at UMDA. Because of the climate at UMDA (semi-arid cold desert) and sparse flora, very little work was required to prepare the site for activity. This cost may differ at another facility with rugged terrain or heavy vegetation or both. Managers considering project design and project costs should weigh the cost of treating onsite versus transporting soil to a more suitable site for composting, if they expect extensive site work.

RA-WBS category element 33.03.90 represents another instance where a lump sum entry was provided by WCC under the heading "General Field Requirements" with no further clarification. The standard RA-WBS does not include such a heading, therefore, it was grouped under site work, given its name, but was entered as a 9x or "nonstandard element" in the RA-WBS. Due to lack of data, no further cost differentiation was possible in this area.

The chain of events associated with the increased soil volume, described in Chapter 3, initially appears in the Phase I RA-WBS work area 33.02, Monitoring, Sampling, Testing, and Analysis under category element 33.02.09, as additional sampling totaling $9,920. The increased excavation and transport costs for this additional soil appear later in RA-WBS work area 33.08—Solids Collection and Containment under subelements 33.08.01—Excavation of Contaminated Soil, 33.08.90—Screening, and 33.08.91—Transport Contaminated Soil to Storage Building. Although dispersed between the three subelements, this activity accounted for the most significant contract modification to Phase I.

4.4 Cost Breakdown—Phase II

Each of the eight general work areas appearing in the RA-WBS for Phase II is represented in Table 4-3, indicating activity, total cost, percentage of Phase II cost, and percentage of the combined Phase I and II costs ($5,131,106). Table 4-3 also identifies the cost elements, or activities, as fixed or variable costs. Figure 4-2 graphically identifies the primary cost elements in Phase II.

Figure 4-3 illustrates total project cost including Phase I, Phase II, and all work on behalf of USACE in preparing, supervising, and administering the Remedial Action Contracts.

Table 4-3. Phase II Cost Breakdown

Work Area	Activity	Cost	% of Phase II Cost	% of Phase I and II Cost
33.01	Mobilization and Preparatory Work [1]	$1,258,701	33.03%	24.53%
33.02	Monitoring, Sampling, Testing, and Analysis [2]	$423,481	11.11%	8.25%
33.03	Site Work [1]	$20,000	0.52%	0.39%
33.11	Biological Treatment [2]	$1,989,454	52.20%	38.77%
33.19	Disposal (Commercial) [1]	$8,950	0.23%	0.17%
33.20	Site Restoration [1]	$9,960	0.26%	0.19%
33.21	Demobilization [1]	$78,480	2.06%	1.53%
33.90	Settle Miscellaneous Claims [2]	$21,918	0.58%	0.43%
PHASE II TOTAL COST		**$3,810,944**		**74.27%**
TOTAL COST PHASE I&II		**$5,131,106**		

Notes:
1 Fixed Costs
2 Variable Costs

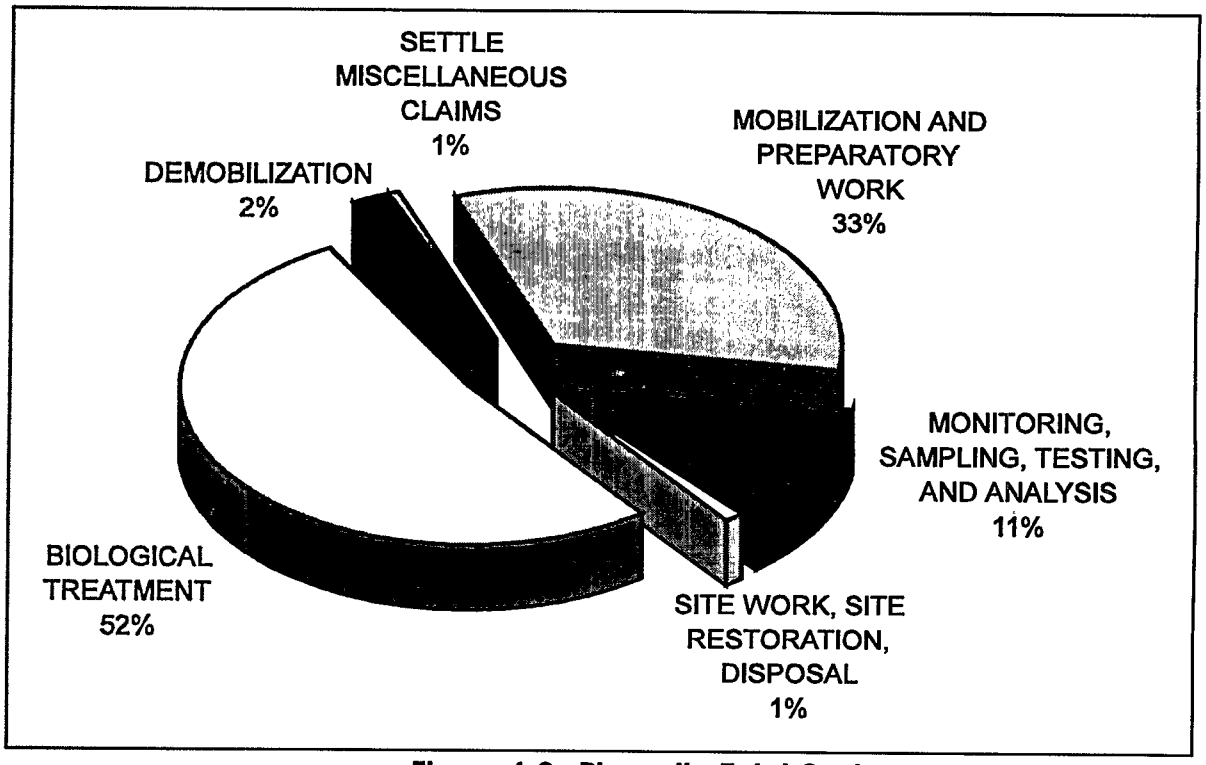

Figure 4-2. Phase II—Total Cost

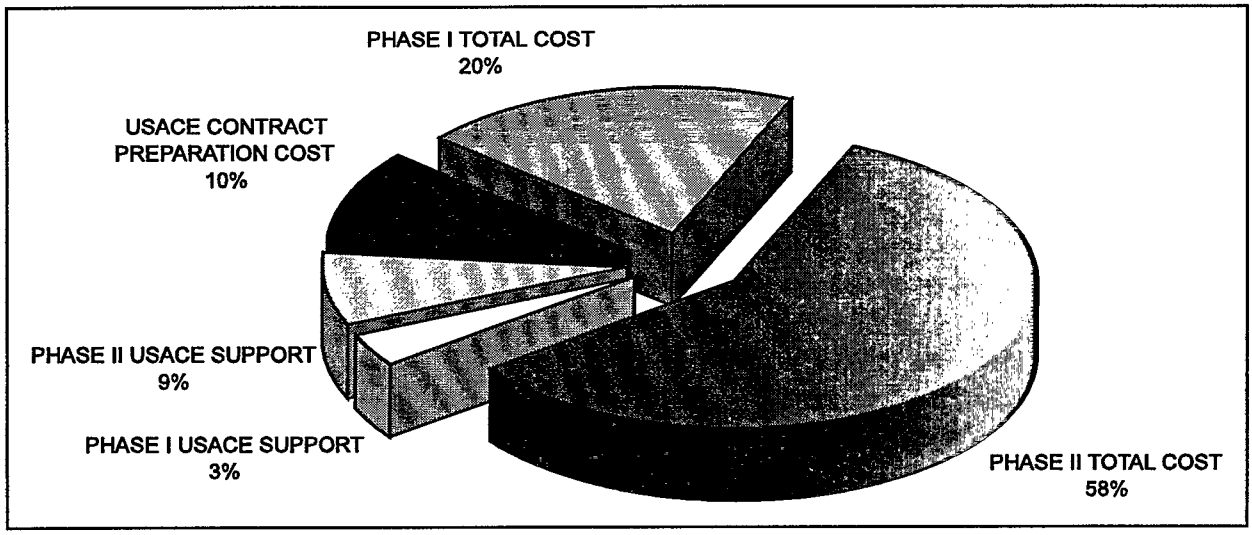

Figure 4-3. Total Cost by Phase

The three largest areas of cost concentration occurring in Phase II include Biological Treatment at 52 percent, Mobilization and Preparatory Work at 33 percent, and Monitoring, Sampling, Testing and Analysis at 11 percent. The balance of the general work areas in Phase II comprise four percent of the Phase II cost (Demobilization at two percent, Site Work, Site Restoration and Disposal [Commercial] at one percent, and Settlement of Miscellaneous Claims at one percent).

Given that the primary thrusts of Phase II were to perform (1) trial tests to ascertain optimization of amendment mixture, equipment, and operating procedures; (2) full-scale production composting; and (3) demobilization and restoration, the cost elements of biological treatment, mobilization, and preparatory work and analytical chemistry are consistent with the tasking.

As mentioned in Chapter 2, much of the duplicative effort occurred at the beginning of Phase II. Within the RA-WBS category elements 33.01.03 through 33.01.05, numerous instances of duplication are evident. Considerable duplicative effort and cost might have been avoided if a single procurement had been used.

Furthermore, the chain of events associated with the increased soil volume resurfaces in RA-WBS category element 33.01.04—Setup/Construct Temporary Facilities, where the $486,970 for leased storage tents appear. This item constitutes the second largest modification to the Phase II contract, surpassed only by the $697,642 cost increase for the biological treatment and testing of the additional soil. Another expenditure that was incurred as a result of the additional soil excavation was the cost of transferring it from the temporary pile into the storage tents. This activity cost $66,101.

RA-WBS category element 33.02.06—Sampling Soil and Sediment (onsite analysis) and RA-WBS category element 33.02.09—Laboratory Chemical Analysis represent additional cases where only lump sum entries were provided by BSI with no further clarification. Although dedicated categories exist within the standard RA-WBS for each of the entries, further detail pertaining to cost per sample and number of samples taken would be helpful in future cost estimating.

4.5 Unit Cost Breakdown

Unit cost for the UMDA remediation by windrow composting is $346 per ton of contaminated soil (Total Phase I and Phase II cost: $5,131,106 ÷14,808 tons of contaminated soil). Tonnage was derived using 100 pounds per cubic foot of soil present at the site, as communicated via phone by U.S. Army Corps of Engineers on June 20, 1996 (6).

4.5.1 Lowest Unit Cost Possible

The use of two contractors at UMDA resulted in some duplication of effort, and therefore costs. Although this two-phase approach at UMDA was unavoidable, other sites should attempt to use a single contractor for both excavation and remediation. The unit cost of $346 per ton of contaminated soil at UMDA incorporates this duplication of costs, particularly in the areas of Mobilization and Preparatory Work, Site Restoration, and Demobilization. In addition, the lack of interface between the two contractors resulted in additional work and added costs (e.g., re-screening the soil, temporary storage tents). By theoretically eliminating (or reducing) some costs associated with duplicated efforts, the unit cost could be as low as $299 per ton of contaminated soil at UMDA.

A single contractor would require only one mobilization, one site restoration, and one demobilization. At UMDA the demobilization of Phase I and the mobilization of Phase II caused some significant overlap. RA-WBS work category 33.01, Mobilization and Preparatory Work for Phase I could be reduced by $154,000, retaining the higher cost of mobilization in Phase II plus the costs for the RAMP in Phase I. Though a single contractor may only prepare a single RAMP to address both excavation and remediation, that RAMP would be extensive; thus, the cost of preparing the additional RAMP in Phase I is retained in the mobilization cost. RA-WBS work categories 33.20 and 33.21, Site Restoration and Demobilization, could be reduced by $9,960 and $5,000, respectively (these reductions are the lower of Phase I and Phase II costs for these elements).

Additionally, there are some costs in Phase II that are incurred as a result of the lack of interface between the two contractors. Because Phase I work started before the Phase II contract was awarded, WCC could not anticipate the appropriate size of the CSSB to accommodate the size and turning radius of BSI's specialized equipment. The lease of the temporary tents ($486,970) was somewhat excessive, considering that the overflow of excavated soil was adequately stored outside with a reinforced 18-mil polyethylene liner for cover on an asphalt pad by the Phase I contractor. The contaminated soil in the soil storage building could have been stored in a similar

fashion, with a reduced cost. This would also reduce the cost of transferring the soil (say, in half) by only moving soil in the building.

Alternatively, a future contractor may evaluate the feasibility of simultaneously excavating and remediating. A backhoe operator would excavate one batch of soil at a time for processing. During the biodegradation period of a batch, onsite analysis could be done in the contaminated area to identify the area to excavate for the next batch. This "assembly line" approach would eliminate the need for any storage facility.

Finally, the Phase II contractor had to re-screen the contaminated soil because the Phase I contractor (already paid in full by USACE to do the screening) did not screen to an adequate particle size. This screening added $16,000 to the Phase II contract, which could have been avoided with a single contractor.

Table 4-4. Potential UMDA Cost Savings

WBS #	Activity	Cost
33.01.04	Mobilization and Preparatory Work: Setup/Construct Temporary Facilities	$154,000
33.20	Site Restoration	$ 9,960
33.21	Demobilization	$ 5,000
33.01.04.91	Temporary Storage Tents	$486,970
33.01.90	Transfer Soil into Storage Tents	$ 33,050 (50% of $66,101)
33.01.91	Additional Screening to Remove Concrete Debris	$ 16,000
	TOTAL Potential Cost Savings	$704,480

Considering the potential cost savings identified in Table 4-4, above, the unit cost of the UMDA windrow composting could be as low as $299 per ton of contaminated soil, a 14% cost savings.

4.5.2 Unit Variable Cost

Unit cost has been used in this report to mean total cost of remediation per ton of contaminated soil. In addition, each cost element and subelement can be broken into a unit dollar cost. In Appendices A and B, unit costs are provided for variable cost elements such as amendments and analytical testing, so that they may be applied to other sites. Alternatively, fixed costs are generally provided in a lump sum value. At UMDA, fixed costs account for 58% ($2,165,385) of the combined Phase I and Phase II total cost. This value represents the minimum cost to operate before any soil is treated.

Table 4-5 identifies some of the variable cost elements, with the associated unit cost. Managers of other sites similar to UMDA can estimate variable costs by scaling the unit variable costs, shown below in Table 4-5, according to number of samples, volume of soil, etc. Some unit costs

below will vary at different sites according to different factors (e.g., test methods used, types of amendments used, availability of amendments, etc.).

Table 4-5. Examples of Unit Variable Costs at UMDA

WBS #	Activity	Units	Cost/Unit
33.02.06	Sampling Soil and Sediment (onsite analysis)		
	First 61 Samples	EA	$ 28
	Over 61 Samples	EA	$ 25
33.02.09	Laboratory Chemical Analysis		
	First 42 Samples	EA	$ 225
	Over 42 Samples	EA	$ 250
33.08.01	Excavation of Contaminated Soil	CY	$ 17
33.08.90	Screening	CY	$14.02
33.08.91	Transport Contaminated Soil to Storage Building	CY	$ 5.59
33.11.07.01.08	Amendments	LS	
	Sawdust	CY	$16.75
	Alfalfa	TON	$109.00
	Chicken Manure	TON	$48.45
	Cow Manure	TON	$16.00
	Potato Waste	TON	$22.50

4.6 Sensitivities

A number of factors can directly or indirectly affect costs. These factors include physical parameters such as climate, soil characteristics, and contaminant level as well as economic parameters such as labor rates, availability and cost of amendments, and site accessibility and infrastructure. Some of these factors are discussed below.

Climate and Soil

At UMDA, the semi-arid cool climate—coupled with the sparse vegetation of grasses and low brush—allowed for a fairly low preparatory site work cost. The soils, which generally consist of fine to coarse sands and gravels with an occasional lens of silt, were also readily excavated. Other sites will naturally vary in climate (precipitation, temperature, wind conditions, and relative humidity) and soils (clay content, rock, and chemistry). The sites will therefore require more extensive clearing, grading, and excavation with higher associated cost.

Labor

The cost of labor can vary considerably by location. Qualified equipment operators are required to operate all the machinery used in the windrow composting process. Typically, when heavy construction equipment is bid, the price includes the operator; however, at UMDA the "maulwalf" and "Wendy" machines were classified as specialized equipment and commanded an even higher premium for their operation. Attention should be given to becoming familiar with applicable wage rates in the region of activity and ensuring qualified individuals are available.

Amendments

Amendment availability and cost are significant when reviewing composting cost variables. Two important considerations are the proximity and seasonality of the materials to be used. At UMDA, the majority of the amendments were readily available in the Umatilla area. Several large potato processors were nearby, and processing occurred year-round. The adjoining counties also contained a number of livestock feedlots, making cow manure readily available. A large commercial egg supplier was present in Pasco, Washington, where a constant supply of chicken manure was available; however, transportation from the supplier for all amendments to the site (approximately 50 miles) did influence cost. Alfalfa was grown locally with harvest occurring from late June to early September. Alfalfa was available year-round, but in limited quantities and elevated prices. Sawdust was the most difficult amendment to obtain because logging operations had ceased in the immediate vicinity. Although relatively unaffected by seasonal changes, the sawdust had to be transported from Hood River, Oregon, a distance of approximately 100 miles, thereby influencing its cost. Availability, seasonality, and quality and consistency are equally important when considering amendment materials and sourcing.

Site

Site location, accessibility, and infrastructure also contribute to cost. Terrain posed little or no difficulty at UMDA, given the modest relief characteristics, and even though the setting is rural, an adequate infrastructure is present. Paved roads are within a mile of the lagoons, with gravel roads covering the remaining distance. Sufficient water is available from the installation hydrant system, while a transformer, installed at the lagoons and tied into existing service, provides necessary power. Interstate access is immediate; UMDA is situated at the intersection of I-82 and I-84. The site should be fairly level to avoid costly earthwork and preferably cleared for the same reasons. The increase in the volume of treated soil due to the addition of 70 percent amendment should also be considered for its impact on redisposition at the site. An area within close proximity to the contaminated area would be ideal for site setup to avoid long hauling distances.

5.0 Conclusions and Recommendations

The purpose of this report is to document the costs for the first full-scale use of windrow composting to treat explosives-contaminated soils at UMDA. A previous preliminary analysis conducted for a small-scale demonstration study at UMDA estimated the unit cost for windrow composting at $326 per ton of contaminated soil for 10,000 tons of soil over a project duration of 2 years (8). This report concludes that the unit cost for full scale remediation at UMDA is $346 per ton of contaminated soil for 14,808 tons of soil over a project duration of two and a half years (from mobilization of Phase I to demobilization of Phase II). Although this report does not attempt to make an economic comparison of windrow composting to incineration, it clearly demonstrates the cost-effectiveness of this innovative technology over its historic alternative (estimated cost for incinerating approximately 14,000 tons of contaminated soil is $540 per ton [4]).

The cost data for this remediation work is presented using the RA-WBS. Table 5-1 below identifies the largest cost elements of the RA-WBS for the UMDA remediation.

Table 5-1. Summary of Largest Cost Elements

WBS Item	Activity	% of Total Phase I and Phase II Cost
33.11	Biological Treatment	39%
33.01	Mobilization and Preparatory Work	25%
33.03	Site Work	10%

The total Phase I and Phase II cost ($5,131,106) does not include the USACE cost for support (engineering, supervision, administration) and contracts (Invitation for Bid in Phase I and Request for Proposal in Phase II). The USACE total cost for "doing business" (support and contracts) at UMDA was significant at $1,385,000, or 21% of the total project cost (Phase I plus Phase II plus USACE costs). USACE costs represent fixed costs. Mobilization and Preparatory Work and Site Work also represent fixed costs that are independent of project duration or volume of contaminated soil to be treated. Biological treatment costs will vary according to site specific variables (e.g., nature and extent of contamination, soil characteristics, amendments availability, and regional labor rates) and processing rates.

Based on the results presented in this report, managers of other sites with explosives-contaminated soils can estimate the cost of remediation using the windrow composting technology. Estimates will come closest to actual costs for sites with similar site conditions (contaminated soil volumes, climate, soil type) and similar remedial action goals as UMDA. Estimates for sites with different conditions and different remedial action goals must scale subelement costs according to individual site characteristics.

In addition to documenting cost, this report provided some recommendations for possibly optimizing cost at future remediation sites. Those recommendations are re-iterated here:

- In accordance with contract requirements, the remediation contractor should perform on-site trial tests prior to full-scale production composting to: (1) ensure proper equipment operation; (2) determine effectiveness of treatment; (3) correlate field data from onsite analysis (Methods 8515 and 8510 or alternatively, Methods 4050 and 4051) with laboratory data (Method 8330); and (4) determine optimal amendments mixture, loading rate, and turning frequency. At UMDA, incorporation of trial test results increased processing rates, reduced treatment times, and created the potential for significant savings.

- Since the loading rate of amendments (70%) to contaminated soil (30%) is high, the contractor may select the specific amendments to substantially reduce cost. Both the unit amendment cost and their combined effect on reducing the composting process time reduce overall cost. For windrow composting, the contractor selects amendments based on a number of criteria including, but not limited to: carbon to nitrogen (C:N) ratio, moisture content, pH, homogeneity, texture, porosity, total metabolic energy, rate of carbon substrate use, seasonal availability, regional availability, and cost.

- Although the use of two contractors was unavoidable at UMDA, it is not recommended for future remediation sites. The USACE was approaching a deadline imposed by CERCLA to begin on-site remedial action within 15 months of the issuance of the September 1992 ROD. To avoid a NOV and other penalties, the USACE opted to perform the work in two phases. Therefore the Phase I and Phase II contractors duplicated certain cost elements (e.g., Mobilization and Preparatory Work, Site Work, Site Restoration, Demobilization). This duplication of effort is reflected in the costs.

- For future cost reporting of windrow composting operations, contractors should use the RA-WBS and report costs for subelements to the lowest level of detail to refine the effects of site-specific variables.

6.0 References

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(2) Bioremediation Services Incorporated (BSI). *Phase II Contaminated Soil Remediation Explosives Washout Lagoons, Umatilla, Oregon.* Contract No. DACA67-94-C-0031. Best and Final Offer (BAFO). March 1994.

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(8) U.S. Army Environmental Center (USAEC). *Windrow Composting Engineering/Economic Evaluation.* Report No. CETHA-TS-CR-93050. Prepared by Roy F. Weston Inc. May 1993.

(9) U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). *Feasibility Study for the Explosives Washout Lagoons (Site 4) Soils Operable Unit. Umatilla Depot Activity (UMDA) Hermiston, Oregon.* Final Report. Report No. CETHA-BC-CR-92017. Prepared by CH2M Hill and Morrison Knudsen Environmental Services. April 1992.

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(11) Wilder Construction Company. *Phase I, Contaminated Soil Remediation, Explosives Washout Lagoons, Umatilla, Oregon.* Contract No. DACA67-93-B-0088. Final Remedial Action Management Plan (RAMP). June 1994.

Report Preparation Information

Cost Report: Windrow Composting to Treat Explosives-Contaminated Soils at Umatilla Army Depot Activity (UMDA), Report No. SFIM-AE-ET-CR-96184, Contract No. MDA 970-89-C-0019, Subtask 04-26, September 1996.

Prepared for: U.S. Army Environmental Center (USAEC), SFIM-AEC-TSD, Aberdeen Proving Ground, MD 21010-5401 and Defense Evaluation Support Activity (DESA), 2251 Wyoming Boulevard, S.E., Kirtland AFB, NM 87117-4658.

Prepared by: TRW Inc., 1755 Jefferson Davis Highway, Crystal Square 5, Suite 202, Arlington, VA 22202 and Walcoff & Associates Inc., 12015 Lee Jackson Highway, Suite 500, Fairfax, VA 22033.

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

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

Case Study Abstract

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%.

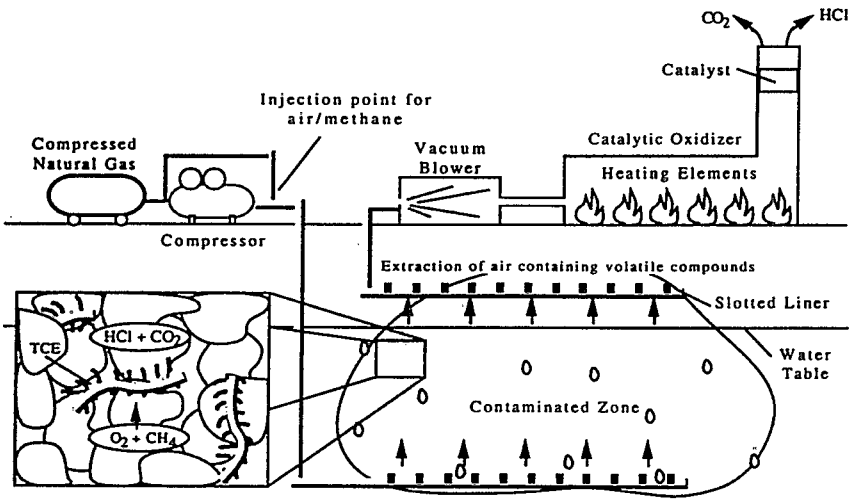
SECTION 1

SUMMARY

Technology Description

In Situ Bioremediation (ISB), which is the term used in this report for Gaseous Nutrient Injection for In Situ Bioremediation, remediates soils and ground water contaminated with volatile organic compounds (VOCs) both above and below the water table. ISB involves injection of air and nutrients (sparging and biostimulation) into the ground water and vacuum extraction to remove VOCs from the vadose zone concomitant with biodegradation of VOCs.

The innovation is in the combination of 3 emerging technologies: air stripping, horizontal wells, and bioremediation via gaseous nutrient injection with a baseline technology, soil vapor extraction, to produce a more efficient in situ remediation system.



- Horizontal wells provide a more effective access to subsurface contamination.
- The air sparging/gaseous nutrient injection process eliminates the need for surface ground water treatment systems and treats the subsurface, both unsaturated and saturated zones, in situ.
- The air sparging/gaseous nutrient injection process stimulates the growth of indigenous microorganisms in the contaminated zone to degrade and mineralize VOCs. Soil vapor extraction can be combined with the injection process to strip the higher concentration, more easily removed contaminants from the subsurface. The injection/extraction system can be designed to meet site specific needs.
- The types of sites most likely to apply ISB will contain moderately permeable, relatively homogenous sediments contaminated with VOCs, especially if both an extraction and injection component is utilized. However, the presence of clay strata does not preclude its use. In fact, the bioremediation component may be well applied to enhance degradation and/or removal of VOCs from lower permeability zones.

Technology Status

A full-scale demonstration was conducted as part of the Savannah River Integrated Demonstration: VOCs in Soils and Ground Water at Nonarid Sites.

U.S. Department of Energy
Savannah River Site
M Area Process Sewer/Integrated Demonstration Site
Aiken, South Carolina
February 1992 to April 1993

- A group of nationally recognized experts from the U.S. Department of Energy (DOE), the U.S. Air Force, the U.S. Geological Survey, the U.S. Environmental Protection Agency, industry, and academia met regularly for 3 years to provide unique insights for planning, execution, and evaluation of this technology demonstration.

The demonstration site was located at one of the source areas within the one-square mile VOC ground water plume. Prior to application of ISB, trichloroethylene (TCE) and tetrachloroethylene (PCE) concentrations in ground water ranged from 10 to 1031 ug/L and 3 to 124 ug/L, respectively. TCE and PCE concentrations in sediments ranged from 0.67 to 6.29 mg/kg and 0.44 to 1.05 mg/kg. The site is underlain by a thick section of relatively permeable sands with thin lenses of clayey sediments. Appendix A describes the site in detail.

Key Results

- Almost 17,000 lbs. of VOCs were removed or degraded over 384 days of operation. The vacuum component of ISB removed 12,096 lbs. VOCs and the biological component degraded and mineralized an additional 4,838 lbs. VOCs.
- Mass balance calculations indicate that bioremediation destroyed 40% more VOCs than simple air sparging (i.e, in situ air stripping).
- Gaseous nutrient injection of carbon, nitrogen, and phosphorus was achieved simultaneously for the first time and demonstrated better mass transfer than previous methods of liquid nutrient injection.
- This nutrient injection strategy stimulated a specific functional group of bacteria that is known to degrade specific contaminants.
- No toxic intermediates were produced by the bioremediation strategy. Contaminants were completely mineralized.
- The best operating campaign used continuous air and nutrient injection (N & P) plus the pulsed addition of 4% methane.
- Los Alamos National Laboratory (LANL) completed a cost-benefit analysis showing that ISB could reduce costs by over 30% compared to the baseline technology of an integrated Soil Vapor Extraction/Pump- and-Treat System (SVE/PT).
- ISB could reduce the time required to remediate a site by 5-7 years compared to the baseline technology of SVE/PT.

The ISB process is patented by the Department of Energy and has been licensed to six commercial vendors with 13 new applications pending. Two companies are using the technology in the field. Licenses are available through the Westinghouse Savannah River Company (WSRC).

Contacts

Technical

Terry Hazen and Brian Looney, Principal Investigators, WSRC, (803) 725-6413 and (803) 725-3692.

Management

Kurt Gerdes, DOE EM-50, DOE Integrated Demonstration Program Manager, (301)903-7289.

Jim Wright, DOE Plumes Focus Area Implementation Team Manager, (803)725-5608.

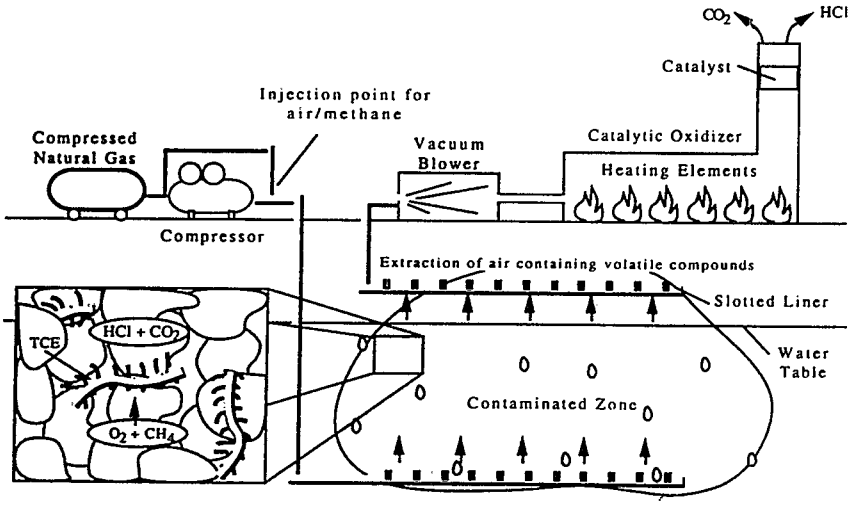
Licensing Information

Caroline Teelon, Technology Transfer Office, WSRC, (803)725-5540.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Schematic



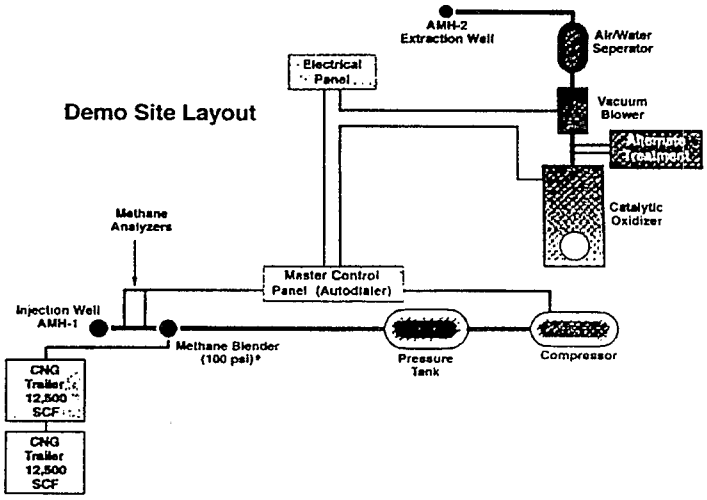
- Air, methane, nitrous oxide, and triethyl phosphate were injected through the lower horizontal well, below the water table.
- An air/contaminant mixture was extracted from the upper horizontal well, above the water table.
- Offgas treatment used catalytic oxidation for the demonstration, but other technologies are available for the treatment of offgases.
- Indigenous methanotrophic bacteria can oxidize methane via a series of enzymes (e.g., methane monooxygenase). Methane monooxygenase, an extremely powerful oxidizer, induces the formation of TCE-epoxide from TCE. TCE epoxide is extremely unstable and spontaneously breaks down. The final and almost immediate end product is carbon dioxide and chloride salts.

Appendix B provides detailed information about the horizontal well installations and the monitoring wells installed.

Aboveground System

Notes:
* Air-water separator removes debris and moisture from the air stream. System includes a day tank to drain water from separator for treatment at M-Area air stripper.

**Demonstration generated VOCs that were treated by electrically heated catalytic oxidation of the offgas.



Process Schematic and Engineering Schematic

SECTION 3

PERFORMANCE

Demonstration Plan

- Performance of the technology has been assessed using information from the full-scale demonstration at SRS. Six different operational modes were tested during the demonstration.
- Major elements of the demonstration included:
  - initial vapor extraction of vadose zone gases (20 days),
  - addition of air sparging by simultaneous air injection into the saturated zone and vapor extraction from the vadose zone (33 days),
  - a planned series of nutrient additions:
    - 1% methane addition (107 days),
    - 4% methane addition (79 days),
    - pulsed 4% methane addition operated at long and short intervals (94 days),
    - continuous addition of gaseous nutrients in the form of 0.07% nitrous oxide and 0.007% triethyl phosphate in air in combination with pulses of 4% methane (94 days).
  - assessment of the behavior of injected methane in air through an inert gas (helium) tracer test, and
  - comparison of microbiological assays for monitoring and control of in situ bioremediation.

Treatment Performance

Summary

- Air-nutrient injection/extraction removed VOCs from the subsurface and degraded VOCs in place.
- Biostimulation and biodegradation occurred in situ without producing toxic daughter products.
  - Increases in indigenous methanotrophs and in CO2 concentrations in soil gas and extraction well gas imply significant microbial community degradation of methane and TCE.
  - Decreases in methane and TCE in the subsurface coincided with increases in densities of methanotrophs (up to 7 orders of magnitude) and free chloride ion as a result of biodegradation.
  - Addition of continuous 4% methane initially stimulated microbial populations but led to nutrient depletion, which then decreased the microbial population.
  - Addition of nitrogen and phosphorus nutrients with pulsed methane resulted in enhanced and sustained microbial growth that optimized bioremediation and mineralization of TCE and PCE in ground water and sediments.
- ISB has demonstrated reduction of VOC concentrations in ground water below the Safe Drinking Water Act maximum of 5 ppb for TCE/PCE. Overall ground water concentrations decreased by as much as 95%.
- Cleanup of VOCs in the vadose zone was very effective. Most sediments contained nondetectable concentrations of VOCs after the demonstration was completed. Soil gas concentrations decreased by more than 99%.
- Average daily emissions from the offgas stream were less than the minimum detection of 1.9 lb./day. Greater than 94% of VOCs were treated by the catalytic oxidation unit.

Key System Parameters

- Horizontal Well Placement
  - The lower injection horizontal well was placed below the water table (120 feet) at a depth of 175 feet with a screened length of 310 feet.
  - The upper extraction horizontal well was placed in the vadose zone above the water table at a depth of 80 feet with a screened length of 205 feet.
- Vacuum Applied
  - Air was extracted continuously from the upper vadose zone horizontal well (AMH-2) at 240 scfm.
- Air Injection
  - Air plus nutrients were injected into the lower aquifer horizontal well (AMH-1) at 200 scfm.
- Nutrient Injection Campaigns
  - 1% methane was initially injected continuously.
  - Methane concentration was increased to 4%.

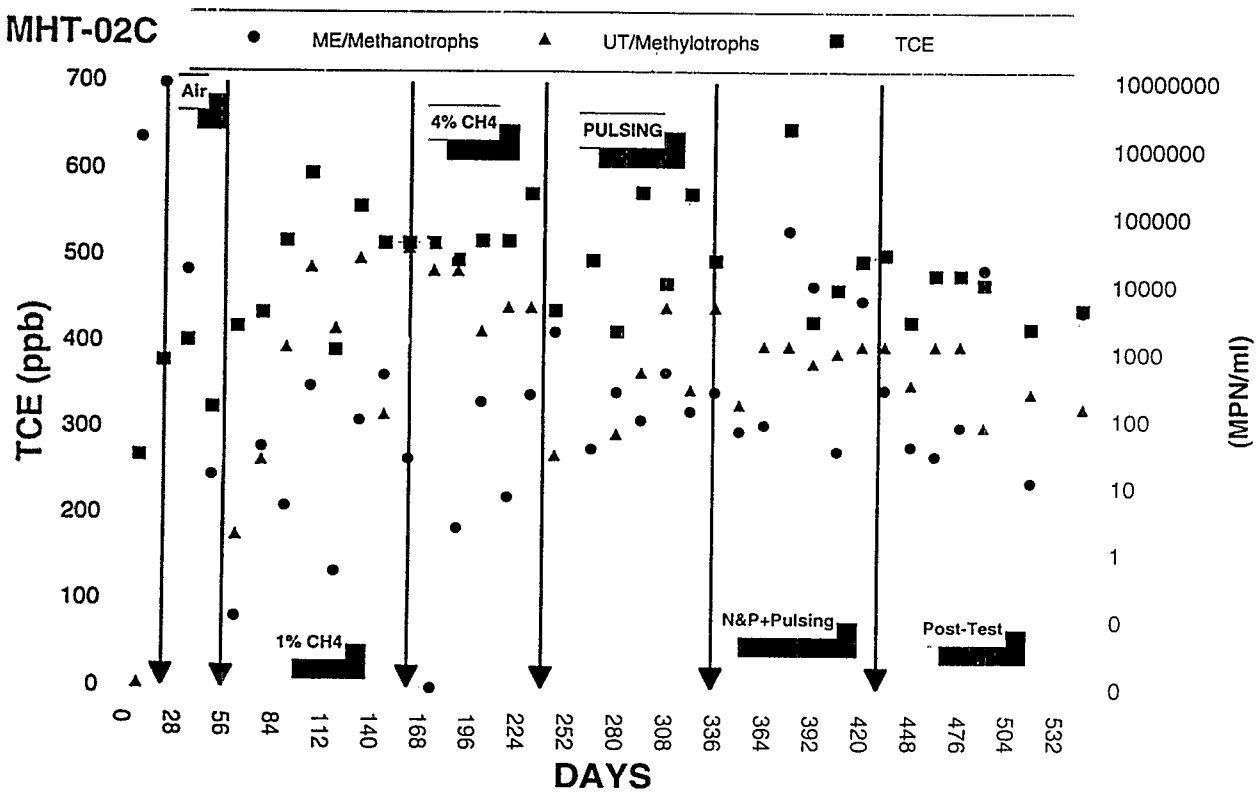
- Methane injection was maintained at 4% but it was applied in pulses.
- Pulsed 4% methane injection was supplemented with continuous injection of 0.07% nitrous oxide and 0.007% triethyl phosphate in air to supply nitrogen and phosphate required for sustained microbial growth and metabolism.

• Microbial Activity
- Prior to ISB, subsurface ground water and vadose zone bacterial populations were low, and the microbial population was under nutrient stress.
- The addition of methane specifically stimulated the growth of methanotrophs, the bacteria primarily responsible for degradation of TCE.

Biostimulation

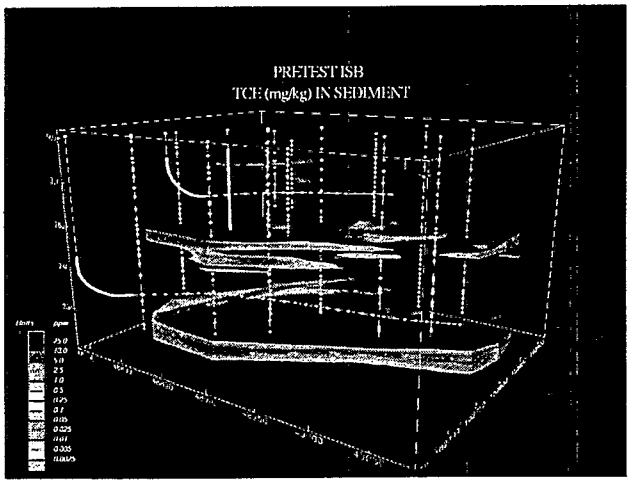
• Evidence of biostimulation: densities of methanotrophs and methylotrophs in the ground water increased as TCE decreased.

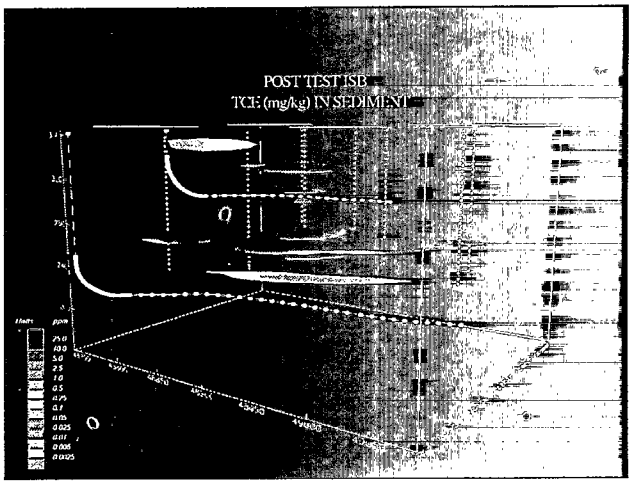
Amount of VOCs Removed or Degraded in Place



• Almost 17,000 lbs. of VOCs were removed over 384 days of operation.
- The vacuum component of ISB removed 12,096 lbs. VOCs and the biological component degraded and mineralized an additional 4,838 lbs. VOCs. Figures showing the concentrations of TCE and PCE in the sediments before and after the demonstration (following) were used to calculate the mass degraded in place.

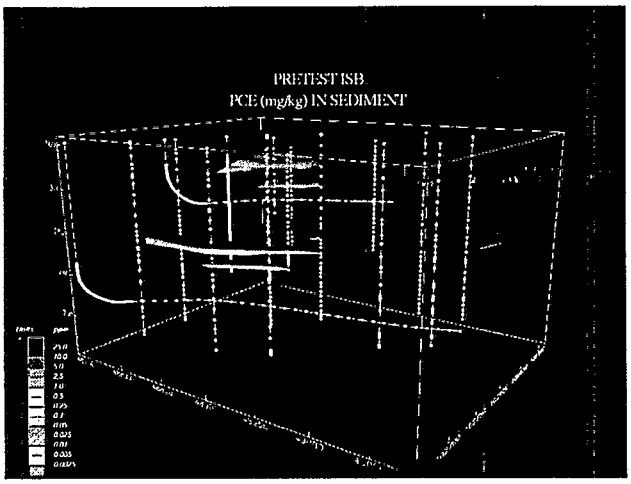
Concentration of TCE in Sediments Before and After ISB

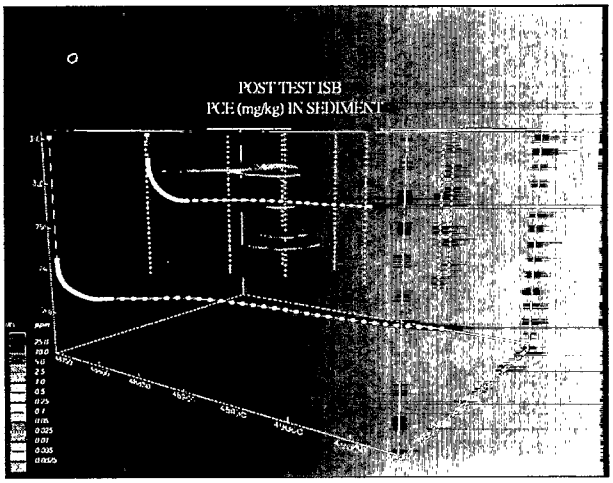




- Sediment data are known to underestimate the amount of VOCs at the demonstration site, but can be used to develop a sense of relative amounts of contamination removed or degraded in place during the demonstration.
- The total sediment inventory for both TCE and PCE decreased by 24%.

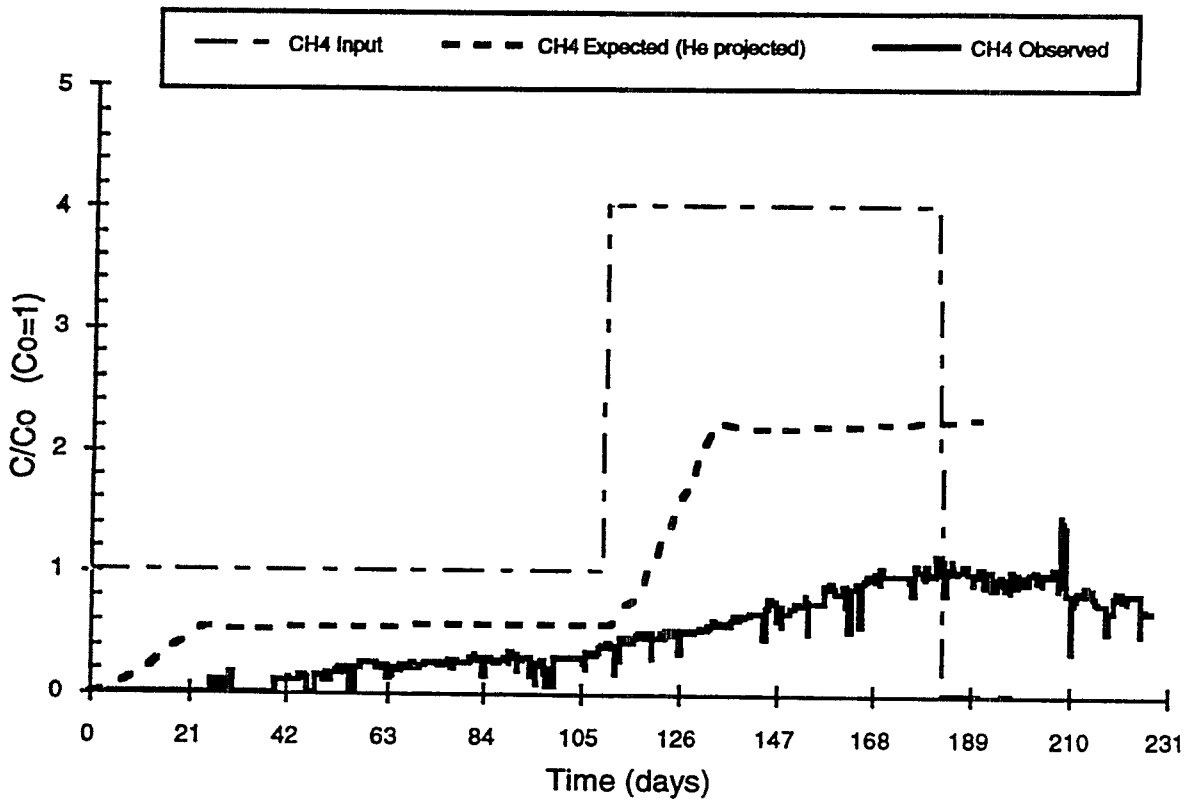
Concentration of PCE in Sediments Before and After ISB





- Sediment data are known to underestimate the VOCs at the demonstration site, but can be used to develop a sense of relative amounts of contamination removed or degraded in place during the demonstration.
- The total sediment inventory for both TCE and PCE decreased by 24%.

Results of Helium Tracer Test



Actual and Predicted Methane Based Upon Helium Tracer Over Time

- A helium tracer test was used to predict the fate of the injected methane.
  - Based on helium breakthrough curves, the amount of methane that should have been observed in the extraction well was calculated.
  - More than 50% of the injected methane was removed before it reached the extraction well.
- Microbial metabolism consumed the methane that did not reach the extraction well.

Zones of Influence

- The extraction well in the vadose zone created a zone of influence estimated to be greater than 200 ft based on pressure measurements.
- Electrical resistance tomography was used to map a sparge zone of influence in the saturated zone. These data showed that flow paths were confined to a complex three-dimensional network of channels, some of which extended as far as 100 feet from the injection well.
- Methane was detected at distances over 500 feet from the injection well.

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

Technology Applicability

- ISB via Gaseous Nutrient Injection has been demonstrated to remediate soils, sediments, and ground water contaminated with VOCs both above and below the water table. The gaseous nutrient injection system can be designed for application only in the unsaturated zone as an add-on to the bioventing process.
- The geometry of horizontal well treatment conforms to typical subsurface contaminated zones, which are often relatively thin but laterally extensive areas.
- ISB is not well suited for extremely low permeability sites if injection and extraction is utilized. Some permeability is required to deliver the nutrients to the indigenous microorganisms.
- At some sites ISB could be most effective when used in conjunction with in situ air stripping, that is in situ air stripping is applied first at a site to quickly remove high concentrations of contaminants from source areas and then ISB is applied as a polishing step to remove contaminants present at lower concentrations. At other sites ISB only would be utilized, thus minimizing the amount of contaminants removed from the subsurface needing treatment as offgas at the surface.
- ISB has demonstrated that it can clean up ground water to drinking water standard concentrations. Sufficient information on cleaning up an entire site to these standards is not available.
- Commercialization and intellectual property information is included in Appendix D.

Competing Technologies

- ISB with Gaseous Nutrient Injection is competitive with conventional baseline technologies of pump-and-treat and pump-and-treat combined with soil vapor extraction. Numerous other physical/chemical, thermal, and biological technologies are also either available or under development to treat VOC-contaminated soils and ground water either in situ or above ground.
- The effectiveness of ISB was compared with performance data from air sparging and soil vapor extraction alone (VOCs removed through the offgas treatment system). This comparison was used as the basis of the cost analysis discussed in Section 5.
- Air sparging in vertical wells and in well recirculation technologies have been implemented at similar sites across the U.S. and in Europe. Thermal technologies have more often been applied at sites with less permeable sediments. Deep soil mixing has been applied at sites with shallower contamination.

Technology Maturity

- Stimulation of indigenous methanotrophic bacteria by injection of methane in water was demonstrated at a small sandy field site at Moffett Field in California, forming the technical basis for the design of this demonstration. However, the Moffett Field demonstration involved addition of nutrients as liquids rather than gases. The SRS demonstration was the first gaseous nutrient injection demonstration designed for stimulation of methanotrophs.
- Much laboratory and bench-scale work has been completed to verify the technical basis for the demonstration.
- ISB via Gaseous Nutrient Injection is currently being applied at two industrial sites and is planned for implementation at the Savannah River Site Sanitary Landfill and the M-Area Integrated Demonstration Site. It has also been proposed at a number of other industrial sites.
- A market survey on horizontal environmental wells was completed in 1993. Key results of that study included:
  - Since 1987, over 100 horizontal environmental wells have been installed in the U.S.
  - 25% of the wells have been used for ground water extraction, 25% for soil vapor extraction, and 50% for other purposes, such as air injection, bioventing, and petroleum recovery.
  - 80% of the horizontal wells have been installed at vertical depths of 25 feet or less.
  - The rate of horizontal well installations has increased significantly in the last two years possibly because of more widespread recognition of advantages and improvements in drilling techniques, which have made installation more cost effective. A cursory update of the 1993 survey has shown that between July 1993 and December 1994 more than 50 horizontal environmental wells were installed.

SECTION 5

COST

Introduction

- Information in this section was prepared from data provided by the SRS VOCs in Soils and Ground Water at Non-arid Sites Integrated Demonstration to the Los Alamos National Laboratory, tasked by the DOE Office of Technology Development to perform an independent cost analysis of the technology being demonstrated.
- The mass of contaminant removed or degraded by in situ biological processes is difficult to quantify.
  - Mass balance determinations relied upon data collected by sampling and analyzing sediment, air, and ground water samples, and by contaminant plume modeling.
- The conventional technology of integrated pump and treat combined with soil vapor extraction (PT/SVE) was used as the baseline technology, against which ISB was compared. To compare the two remediation systems, a number of assumptions were made:
  - PT/SVE would remove the same amount of VOCs as the vacuum component of ISB when operated for the same time period.
  - 4 vertical SVE and 1 PT wells would have the same zone of influence as 2 horizontal wells used for ISB.
  - Volatilized contaminants from both technologies are sent to a catalytic oxidation system for destruction.
  - Capital equipment costs are amortized over the useful life of the equipment, which is assumed to be 10 years, not over the length of time required to remediate a site.

Capital Costs

- Capital costs for the baseline technology are comparable with the innovative technology of ISB.
  - The cost to install horizontal wells for ISB exceeds installation costs of vertical wells. However, horizontal drilling costs are decreasing as the technology becomes more widely used and accepted. If horizontal wells can clean a site faster, significant dollars will be saved on operating costs.
  - Fixed equipment costs for ISB include gas mixing and injection equipment for providing the nutrients required for stimulation of the bioremediation portion of the innovative technology.

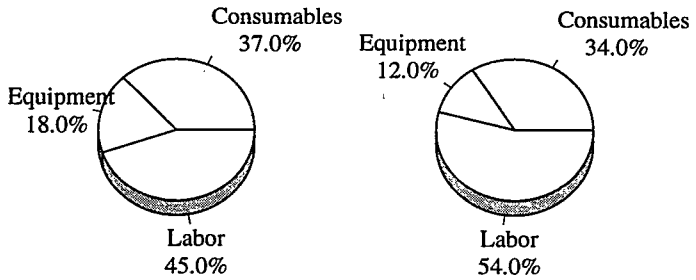
Capital Costs	ISB	PT/SVE
Site Cost	$5,400	$7,500
Equipment Cost	$9200	$32,000
Design and Engineering $1		
Mobile Equipment	$18,000	$18,000
Well Installation	$183,000	$50,690
Other Fixed Equipment	$183,732	$168,665
Mobilization Cost	$43,075	$64,613
Total Capital Equipment and Mobilization Costs	$452,407	$341,468

Operating Costs

- The annual operating costs are comparable between the baseline and the innovative remediation technology.
- However, the treatment time is estimated to be 10 years to remediate the demonstration site using the baseline PT/SVE and only 3 years using ISB. Actual treatment times, are estimates and field experience indicates that the PT/SVE estimate is on the optimistic side, when the objective is the Safe Drinking Water Act (SDWA) maximum of 5 ppb for TCE/PCE.

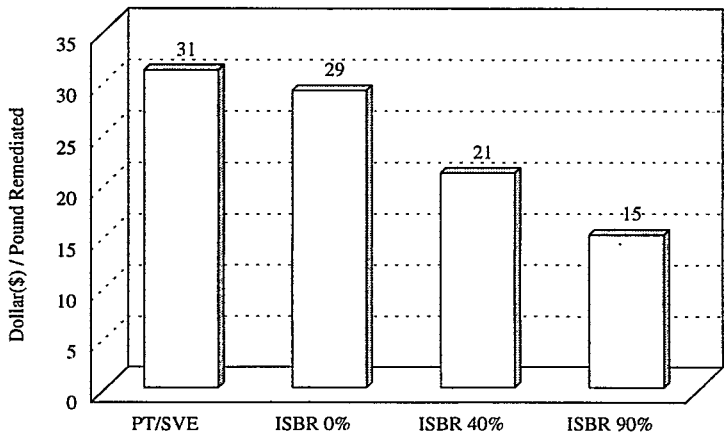
Operation and Maintenance Costs	ISB	PT/SVE
Monitoring/Maintenance	$71,175	$71,175
Consumable Cost	$122,215	$123,595
Demobilization Costs	$43,075	$64,613
Total Operational and Maintenance Costs	$236,465	$259,383

- Consumable and labor costs are approximately 85% of the total cost per pound of the VOCs remediated for both technologies.



ISBR ($21/lb Remediated) PT/SVE ($31/LB Remediated)

- The length of time that the ISB system operated determines the quantity of VOCs remediated. The demonstration was operated for 384 days.
- Mass balances calculated that 41% more VOC destruction occurred with ISB than with air sparging (using the same operating parameters) because of biological remediation.
- A model developed by LANL during the demonstration predicts that after 3 years the quantity remediated would have been 90%.
- The worst case scenario would be no additional destruction because of biological stimulation, but this would still produce a reduction in remediation cost over the baseline technology.



SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

- Permit requirements for the demonstration were controlled by the South Carolina Department of Health and Environmental Control (SCDHEC) and included 1) an Air Quality Permit and 2) an Underground Injection Control (UIC) Permit issued by the South Carolina Board of Drinking Water Protection. A NEPA checklist was also prepared; a categorical exclusion was granted. U.S. Department of Transportation (DOT) certification was required to transport methane to the remediation site.

- Permit requirements for future applications of ISB are expected to include:

  - An air permit for discharge of treated vapor extracted from the subsurface,
  - CERCLA and/or RCRA permitting depending on site specific requirements,
  - Underground injection permits for the injection of methane and nutrients into the subsurface,
  - NEPA review for federal projects, and
  - U.S. DOT certification for transportation of methane to the remediation site.
- Permit requirements will differ from state to state.

- Groundwater protection standards (GWPS) have been established as part of a RCRA permit for the M-Area. The GWPS' are based upon EPA Maximum Contaminant Levels (MCLs). Specific goals for contaminants of greater concern are:

Compound	Concentration (ppb)
TCE	5
PCE	5
TCA	200

Safety, Risks, Benefits, and Community Reaction

Worker Safety

- Health and safety issues for the installation and operation of ISB are essentially equivalent to those for conventional technologies of pump-and-treat or soil vapor extraction.
- Additional permitting and training were required for transportation and delivery of methane and for the operation of the methane injection system.
- Methane concentrations were always far below the explosive limit to minimize any danger to onsite workers. A process hazards review was completed to ensure safe operations.
- Level D personnel protection was used during installation and operation of the system.

Community Safety

- ISB with an operational offgas treatment system does not produce any significant routine release of contaminants.
- No unusual or significant safety concerns are associated with the transport of equipment, samples, waste, or other materials associated with ISB.
- Careful and thorough monitoring of the subsurface sediments and ground water shows that potential harmful or disease-causing microorganisms are not present or stimulated by ISB at the demonstration site.

Environmental Impacts

- ISB systems require relatively little space, and use of horizontal wells minimizes clearing and other activities that would be required to install a comparable vertical well network.
- Visual impacts are minor, but operation of the vacuum blower and compressor create moderate noise in the immediate vicinity.
- Nutritional enrichment does not promote the growth of harmful microbes at the demonstration site.

Socioeconomic Impacts and Community Perception

- ISB has a minimal economic or labor force impact.
- The general public has limited familiarity with ISB; however, the technology received positive support on public visitation days at SRS.
- Bioremediation in general is viewed by the public as a "green" technology, which enhances naturally occurring processes to destroy contaminants.

SECTION 7

LESSONS LEARNED

Design Issues

- Gaseous nutrient injection represents a significant new delivery technique for in situ bioremediation.
- Rates of air extraction (or whether to extract at all) and rates of air/nutrient injection must be tailored to site specific needs.
- The bundle-tube pressure sensors installed along Horizontal Wells 1 and 2 to measure injection/extraction efficiency are inexpensive and recommended for future applications.
- Factors that will control injection protocols, remediation system siting, and monitoring include site geology (especially permeability and heterogeneity), concentrations of native nutrients (such as total organic carbon), natural oxidation potential of the subsurface (i.e. aerobic or anaerobic conditions).
- The filter pack on all the horizontal wells is made up of natural formation solids, principally because of collapse around the borehole. This may diminish well efficiencies. Well design must be tailored to the ultimate use of the well. Prepacked screen should only be used if necessary because it adds significantly to the cost.
- A horizontal well in the unsaturated zone removes water from the formation; the water can collect in the well, reducing its effective length. Wells must be designed to channel water away from low areas.
- Careful alignment of the injection and extraction wells is probably not necessary because the zone of influence of the extraction well is far greater than that of the injection well and because subsurface heterogeneities strongly influence air flow.

Implementation Considerations

- Separate components of the system may be utilized for a particular application or the system may be used in total as demonstrated at the Savannah River Site.
  - For example, the system can be used with or without horizontal wells.
  - Another option involves design of a system that does not have the vapor extraction component. In this case, biodegradation of contaminants is optimized but no contaminants are removed via a physical process.
  - At some sites the addition of methane may not be required at all or at least initially, because there is naturally a sufficient carbon source for the indigenous methanotrophs.
- The optimum operating campaign involved pulsed injection of methane (4%) combined with continuous injection of air with nutrients (nitrogen and phosphorus).
- Automated control and monitoring functions added significantly to the ease and cost of operation of the system.
- A pulsing regime for the gaseous nutrients can be designed to accomplish both aerobic and anaerobic degradation simultaneously. For example, at SRS both TCE and PCE were biodegraded. This required both aerobic and anaerobic degradation. It is believed that anaerobic pockets were created in the subsurface, which led to degradation of PCE within an overall aerobic system.
- Horizontal drilling methods must be tailored to specific site conditions with special considerations for the type of drilling fluid, drilling bit, drilling methodology, casing installation, etc.

Technology Limitations/Needs for Future Development

- Long-term performance data from several years of operation varying operating parameters are required to assess the need for design improvements and to better quantify life-cycle costs.
- Better monitoring methods for determining mass balance and microbiological health of the subsurface population are required to facilitate implementation of ISB.
- It is possible that subsurface injection of gases below the water table can induce ground water flow. In such a case, ISB could accelerate lateral migration of contaminants in certain geologic settings. If clay layers or other geologic features constrict vertical flow, it may be necessary to use ISB in conjunction with a pump-and-treat system for hydraulic control.
- There was no evidence of plugging of the wells as a result of the increased subsurface biomass that resulted from the subsurface injection of nutrient gases.
- More experience with environmental horizontal drilling under a variety of subsurface conditions will ensure better well installations at reduced costs.

Technology Selection Considerations

- The cost of adding methane injection to an air sparging system is relatively low and easily recovered (nearly all water samples showed greater than 90% mineralization of TCE and PCE by methanotrophs after nutrients were added to the system).
- This technology yields significant economic and efficiency gains over conventional baseline technologies for remediation of ground water and sediment contaminated with chlorinated solvents.
- One application of the ISB system can be as a polishing technique after high concentrations are removed by In Situ Air Stripping using horizontal wells. This approach would likely be used at sites where initial contaminant concentrations are high. On the other hand, the biological component may be most effective at sites with lower contaminant concentrations, ultimately targeting attainment of drinking water thresholds.
- The role of horizontal wells in improving the efficiency of remediation was assessed. Remediation efficiency may be enhanced by increased surface area for reaction, similarity of well profile and contaminant plume geometry, borehole access to areas beneath existing facilities, and drilling along facility boundaries to control plume migration. However, each site must be assessed for the utility of horizontal wells.
- Successful ISB requires good contact between injected air and contaminated soils and ground water. An optimal geologic setting would have moderate to high saturated soil permeability, a fairly homogeneous saturated zone to allow for effective injection of gaseous nutrients, and sufficient saturated thickness. Vadose zone characteristics would be moderate to high permeability and homogeneity.
- ISB using horizontal wells may be most applicable in linearly shaped plumes that are relatively thin.

APPENDIX A

DEMONSTRATION SITE CHARACTERISTICS

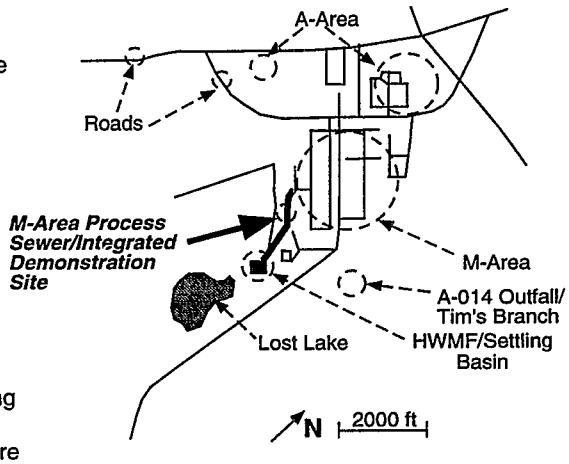
Site History/Background

- The Savannah River Site's historical mission has been to support national defense efforts through the production of nuclear materials. Production and associated research activities have resulted in the generation of hazardous waste by-products now managed as 266 waste management units located throughout the 300 mile² facility.

- The A and M Areas at Savannah River have been the site of administrative buildings and manufacturing operations, respectively. The A/M-Area is approximately one mile inward from the northeast boundary of the 300 mile² Savannah River Site. Adjacent to the site boundary are rural and farming communities. Specific manufacturing operations within the M-Area included aluminum forming and metal finishing.

- The M-Area operations resulted in the release of process wastewater containing an estimated 3.5 million lbs. of solvents. From 1958 to 1985, 2.2 million lbs. were sent to an unlined settling basin, which is the main feature of the M-Area Hazardous Waste Management Facility (HWMF). The remaining 1.3 million lbs. were discharged from Outfall A-014 to Tim's Branch, a nearby stream, primarily during the years 1954 to 1982.

Site Layout



- Discovery of contamination adjacent to the settling basin in 1981 initiated a site assessment effort eventually involving approximately 250 monitoring wells over a broad area. A pilot ground water remediation system began operation in February 1983. Full-scale ground water treatment began in September 1985.

- High levels of residual solvent are found in the soil and ground water near the original discharge locations. Technologies to augment the pump-and-treat efforts, for example soil vapor extraction, ISAS, and bioremediation, have been tested and are being added to the permitted corrective action.

Contaminants of Concern

Contaminants of greatest concern are:

1,1,2-trichloroethylene (TCE)

tetrachloroethylene (PCE)

1,1,1-trichloroethane (TCA)

Property at STP*	Units	TCE	PCE	TCA
Empirical Formula	-	$ClCH{=}CCl_2$	$Cl_2C{=}CCl_2$	CH_3CCl_3
Density	g/cm^3	1.46	1.62	1.31
Vapor Pressure	mmHg	73	19	124
Henry's Law Constant	$atm{*}m^3/mole$	9.9E-3	2.9E-3	1.6E-2
Water Solubility	mg/L	1000-1470	150-485	300-1334
Octanol-Water Partition Coefficient; K_{ow}	-	195	126	148

**STP = Standard Temperature and Pressure; 1 atm, 25 °C*

Nature and Extent of Contamination

- Approximately 71% of the total mass of VOCs released to both the settling basin and Tim's Branch was PCE, 28% was TCE, and 1% was TCA.

- The estimated amount of dissolved organic solvents in ground water in concentrations greater than 10 ppb is between 260,000 and 450,000 lbs and is estimated to be 75% TCE. This estimate does not include contaminants sorbed to solids in the saturated zone or in the vadose zone. The area of VOC-contaminated ground water has an approximate thickness of 150 feet, covers about 1200 acres, and contains contaminant concentrations greater than 50,000 ug/L.

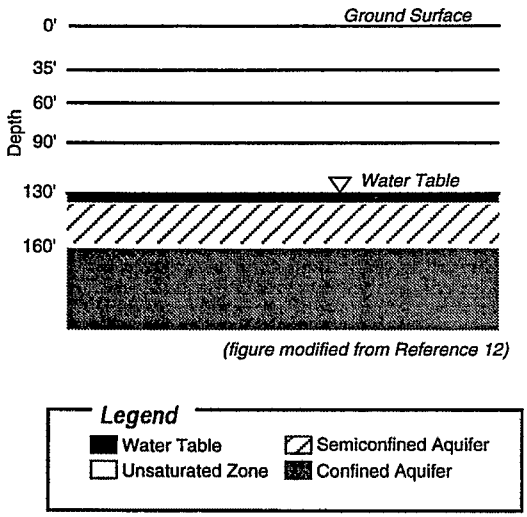
- DNAPLs found in 1991 present challenges for long-term remediation efforts.

- Vadose zone contamination is mainly limited to a linear zone associated with the leaking process sewer line, solvent storage tank area, settling basin, and the A-014 outfall at Tim's Branch.

Contaminant Locations and Hydrogeologic Profiles

Simplified schematic diagrams show general hydrologic features of the A/M Area at SRS.

Vadose Zone and Upper Aquifer Characteristics

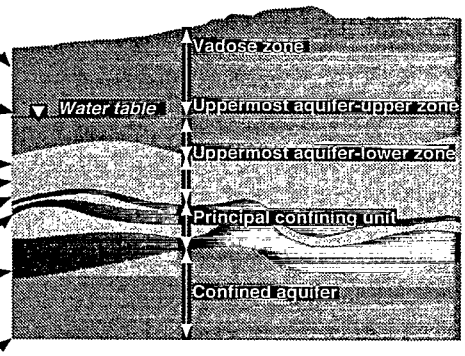


(figure modified from Reference 12)

- Sediments are composed of sand, clay and gravel.
- Clay layers are relatively thin and discontinuous, with the exception of the clay layers at 160-foot depth and a thicker zone of interbedded clay and sand found at 90-foot depth.
- The water table is approximately 135 feet below grade.
- A moderate downward gradient appears to exist beneath the M-Area. Vertical flow rates have been estimated to be 2 to 8 ft/year.
- Radial flow outward from a ground water plateau under most of the A/M-Area exists. Flow is approximately 15 to 100 ft/year.

Hydrogeologic Units

Aquifer Unit	Description	Thickness
Vadose Zone	Poorly sorted mix of sand, cobbles, silt and clay	~57 ft
	Moderate to well-sorted, fine to medium sand containing some pebbles; 13% silt and clay	0-97 ft
	Moderately to well-sorted medium sand; 18% silt and clay	30-55 ft
Water Table Unit	Moderate to well-sorted fine sand with some calcaneous zones; 25% silt and clay; 14% silt and clay beds	16-34 ft
Upper	Well-sorted fine to medium sand; 16% silt and clay; 7% silt and clay beds.	14-60 ft
Lost Lake Aquifer	*Discontinuous clay beds containing 70% silt & clay*	
Lower	Moderate to well-sorted medium sand; 17% silt and clay; 7% silt and clay beds	4-44 ft
Crouch Branch Confining Unit	Clay, clayey silt, and poorly sorted fine to coarse, clayey sand; 62% silt and clay; contains 2 major clay layers the lower of which is 10-56 ft thick and is the principal confining unit for lower aquifer zones	32-95 ft
Crouch Branch Aquifer	Very poorly to well-sorted, medium to coarse sands; 5% sand and clay beds; an important production zone for water supply wells in the M-Area	152-180 ft

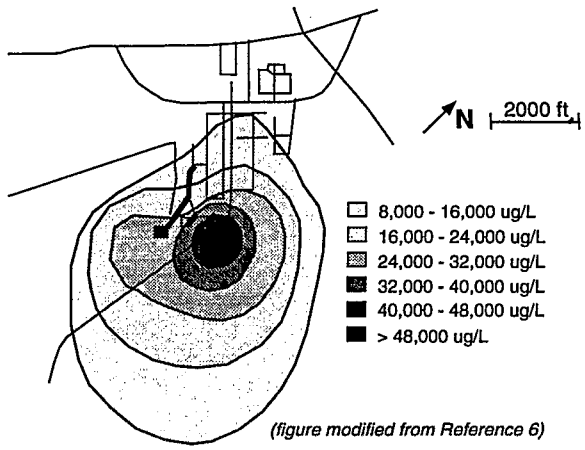


Contaminant Locations and Hydrogeologic Profiles (continued)

Metal-degreasing solvent wastes were sent to the A-014 outfall and, via the process sewer, to the M-Area settling basin. Data from hundreds of soil borings, ground water monitoring wells, and a variety of other investigative techniques have established a well-documented VOC plume in both the vadose and saturated zones.

TCE Ground Water Plume (Top View)

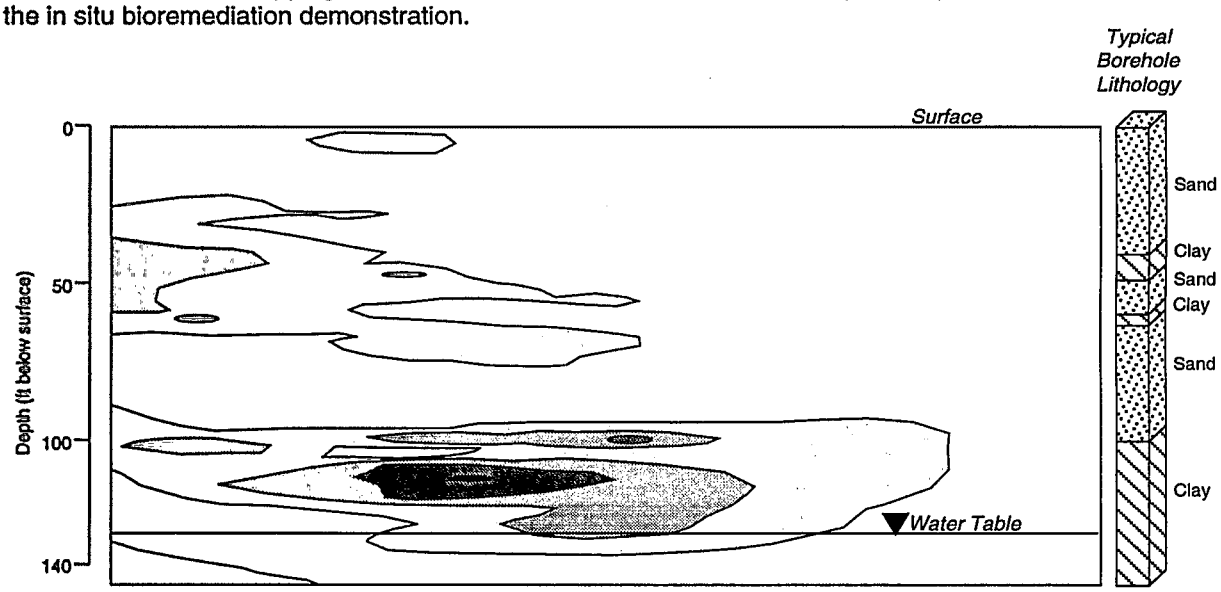
Data from 15 feet below water table in the third quarter of 1990.



(figure modified from Reference 6)

TCE Concentrations in Soil (West-East Cross-Section)

Concentration and lithology data from 1991 along an approximately 200-ft cross-section across the integrated demonstration site. Concentration contours of TCE in sediments are based on analysis of over 1000 sediment samples. Highest concentrations of TCE occur in clay zones. These data were collected before the in situ air stripping demonstration was conducted and do not represent pre-test conditions for the in situ bioremediation demonstration.



(figure modified from Reference 6)

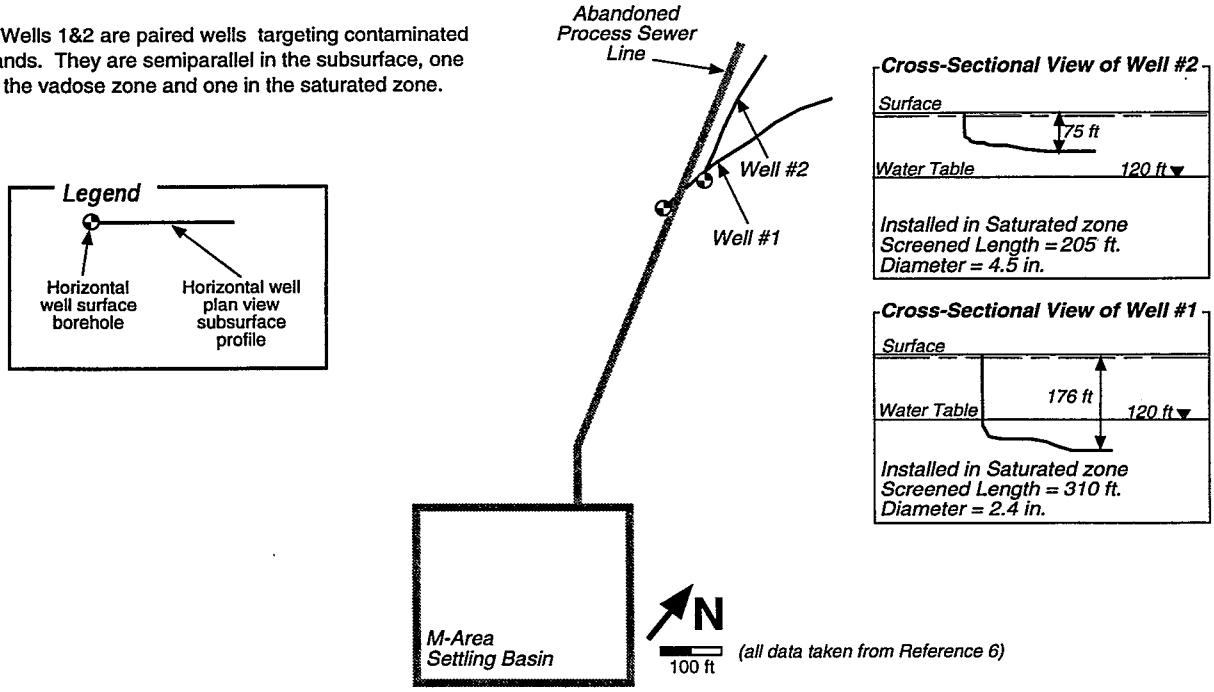
Legend

soil concentrations in ug/kg

- 100 to 1,000 ug/kg
- 1,000 to 5,000 ug/kg
- 5,000 to 10,000 units ug/kg
- >10,000 ug/kg

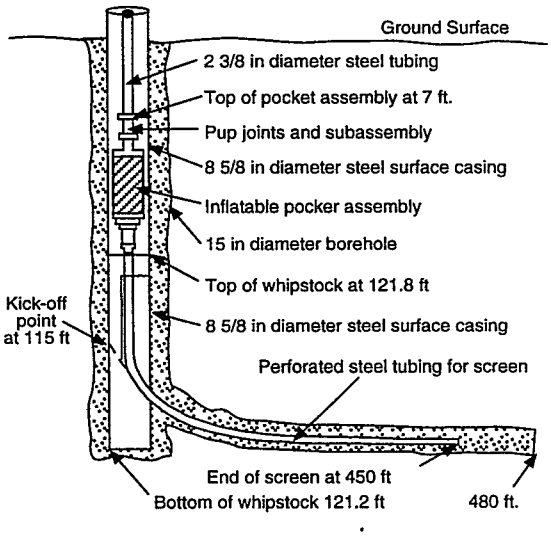
System Configuration

- Wells 1&2 are paired wells targeting contaminated sands. They are semiparallel in the subsurface, one in the vadose zone and one in the saturated zone.

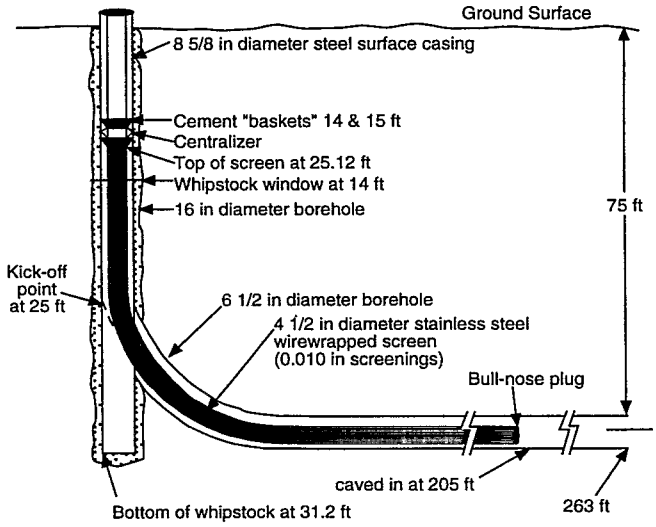


Horizontal Well Close-Ups

Well # 1



Well # 2



Horizontal Well Installation Techniques

The techniques used to directionally drill and install a horizontal well depend on the location and purpose of the well. Petroleum industry technology was used to install Wells 1 and 2 at the Savannah River Site; however, this technology is no longer used. Current installation techniques include the following:

1. **Pipeline/Utility River Crossing System**- Based on a mud rotary system used to drive a downhole drill assembly, including a drilling tool, a hydraulic spud jet with a 2-degree bend to provide directional drilling or a downhole motor depending on the lithology to be drilled.

2. **Utility Industry Compaction System** -Down hole drill assembly consists of a wedge-shaped drilling tool and a flexible subassembly attached to the drill string. The borehole is advanced by compaction, forcing cuttings into the borehole wall. Reduced volumes of water are introduced to cool the drill bit; no circulation of drilling fluid is accomplished.

3. **Hybrid Petroleum Industry/Utility Industry Technology** - Modified mud rotary system with bottom hole assembly comprised of a survey tool, steerable downhole motor, and expandable-wing drill bit. Drilling fluids are used. Curve is drilled and pipe is installed in curve before horizontal is drilled. Only one company provides this type of drilling system.

Operational Requirements

- Design and management of ISB systems require expertise in environmental, chemical, mechanical, and civil engineering as well as hydrogeology and environmental regulations. Automation of system operations with a real-time problem notification system reduced the manpower requirements significantly over that required for the earlier in situ air stripping demonstration. Operation of multiple systems of the scale implemented at the Savannah River Site can be performed by a 1/6 full-time equivalent technician per system. Larger systems or extensive monitoring activities would require additional staff.

Monitoring Systems

Monitoring wells and vadose zone piezometers had previously been installed at the site for the ISAS demonstration.

Ground Water Monitoring Well Clusters

- Twelve borings were completed adjacent to 4-in. monitoring well clusters in the locations shown on the following page.
- One well from each cluster was screened in the water table at elevations ranging from 216 to 244 ft.
- The second well in the cluster was screened in the underlying semiconfined aquifer at elevations ranging from 204 to 214 ft.
- Four borings were completed at two times during the ISB demonstration: after the 1% methane campaign and after the end of the pulsing campaign.

Vadose Zone Piezometer Clusters

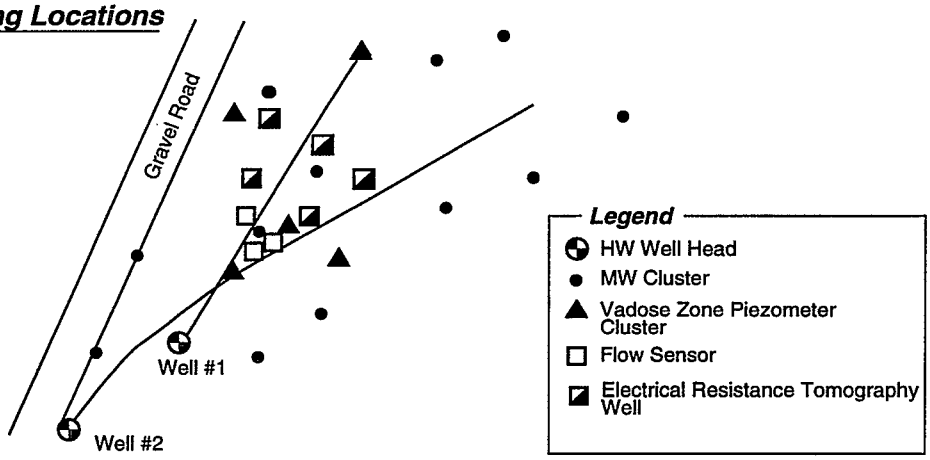
- Three borings were cored adjacent to piezometer clusters in the vadose zone.
- Three piezometer tubes having lengths of approximately 52 ft, 77 ft and 100 ft were installed into each borehole.

Geophysical Monitoring

- ERT was performed in five borings. ERT maps the behavior of subsurface fluids as they change in response to natural or remedial processes.
- Several single-point flow sensors were placed between the injection and extraction wells (just below the water table) to measure ground water flow in the area most affected by the ISB process.

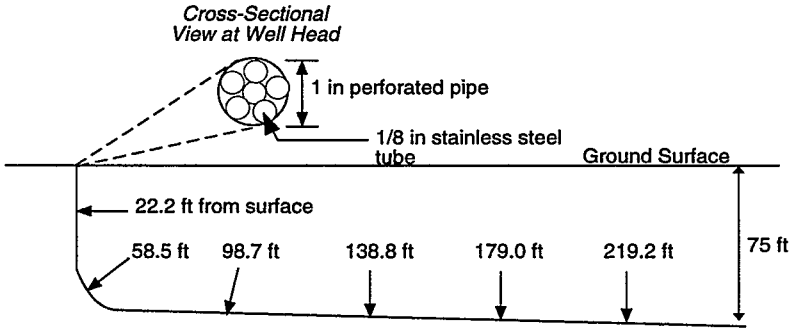
Monitoring Systems (continued)

Sampling/Monitoring Locations



Bundle Tubes

Each horizontal well was filled with a bundle of six tubes encased in a perforated pipe or well screen. Each tube terminated at a discrete distance from the surface for sampling or monitoring at different locations along the well bore.



APPENDIX C

PERFORMANCE DETAIL

Operational Performance

Maintainability and Reliability

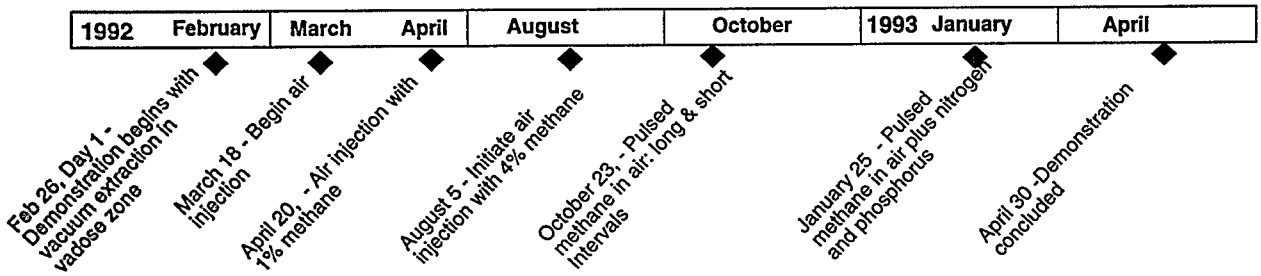
- No functional problems encountered during demonstration; system was operational approximately 90% of all available time.
- Operational performance over long periods (years) not yet available.

Operational Simplicity

- Monitoring performance of ISB is more difficult than monitoring performance of baseline pump-and-treat technology; however, systems have been automated and can be operated and maintained in the field typically by 1/6 full-time equivalent technician. Staffing requirements are detailed in Appendix B.

Demonstration Schedule

Major Milestones of the Demonstration Program



Sampling, Monitoring, Analysis, and QA/QC Issues

Objectives

- Gather baseline information and fully characterize site
- Evaluate removal efficiencies with time
- Evaluate subsurface microbial ecologies
- Identify and evaluate zones of influence

Baseline Characterization

- Baseline characterization was performed before the demonstration to gather information on the geology, geochemistry, hydrology, and microbiology of the site. The distribution of contaminants in soils and sediments in the unsaturated zone and ground water was emphasized. These data were compared with data on soil collected during and after the demonstration to evaluate the effectiveness of ISB.
- Continuous cores were collected adjacent to monitoring well and vadose zone boreholes. Sediments for VOC analysis were collected at 5-ft intervals and at major lithology changes. Samples for microbiological characterization were collected every 10 ft.
- Water samples were collected and analyzed for VOC content and microbial characteristics from monitoring well clusters and at discrete depths adjacent to monitoring well clusters.
- Geologic cross-sections were prepared using gamma ray, sp, resistivity, density, and neutron geophysical logs and core logs.

Sampling, Monitoring, Analysis, and QA/QC Issues (continued)

Sampling & Monitoring	*Location(s)*	*Frequency*	*Technique*
Pressure Monitoring	vadose zone piezometers	weekly	measured at surface using magnehelic or slack-tube macrometer
	injection well	2 x daily	measured at wellhead using pressure gauge
Vacuum Monitoring	extraction well	2 X daily	measured at wellhead using vacuum gauge
	extraction well bundle tubes	weekly	measured at surface
Vapor Sampling	vadose zone piezometers	weekly	sampled through a septum on the vacuum side of a vacuum pump using gas-tight syringes
	extraction well	2 X daily	same as above
	bundle tube	weekly	same as above
Ground Water Sampling	monitoring well clusters	biweekly	sampled using documented Savannah River Site (SRS) well sampling protocols
Microbiological Sampling	monitoring well clusters	biweekly	sampled using documented SRS well sampling protocols
Helium Tracer Test	vadose zone piezometers	weekly	sampled using 500-ml disposable syringes and transferred to 30-ml preevacuated serum vials
	extraction well	2 x daily	

Analytical Methods and Equipment

- Vapor grab samples were analyzed in the field using both a Photo Vac field gas chromatograph (GC) and a GC fitted with flame ionization and electron capture detectors. Analysis was performed immediately after collection.
- Bulk water parameters, including temperature, pH, dissolved oxygen, conductivity, and oxidation reduction potential, were measured using a Hydrolab.
- VOC analysis of water and sediment samples was performed on-site using an improved quantitative headspace method developed by Westinghouse Savannah River Company. Analyses were performed on an HP-5890 GC fitted with an electron capture detector and headspace sampler.
- Helium tracer samples were analyzed using a helium mass spectrometer modified to sample serum vials at a constant rate.

QA/QC Issues

- Vapor samples were analyzed immediately after collection and GC analysis of soil and water samples were completed less than 3 weeks after collection.
- Duplicate analysis was performed for nearly every water and sediment sample collected.
- Approximately 161 samples were analyzed off-site using standard EPA methods to corroborate onsite testing which used the improved quantitative headspace method described earlier. Cross-comparison showed that the quantitative headspace analysis generated equivalent to superior data.
- GC calibration checks were run daily using samples spiked with standard solutions.

Performance Validation

- Samples analyzed onsite by nonstandard EPA methods were sent offsite for confirmatory analysis using EPA methods. Results from these analyses confirmed the findings of Savannah River efforts.
- The effectiveness of horizontal wells for environmental cleanup has been demonstrated by their use in vapor extraction and ground water/free product recovery systems which are also discussed in Appendix D.

APPENDIX D

COMMERCIALIZATION/INTELLECTUAL PROPERTY

Intellectual Property

Primary Sponsor

U.S. Department of Energy, Office of Environmental Management, Office of Technology Development

Existing/Pending Patents

Several parties, including national laboratories, industry, academia, EPA, USGS, USAF, participated in the development and implementation of the ISB system. These participants are listed on the next page.

- Patent 5,326,703, "Method and System for Enhancing Microbial Motility," T.C. Hazen and G. Lopez de Victoria, assignors to the U.S. as represented by the U.S. DOE.
- Patent 5,324,661, "Chemotactic Selection of Pollutant Degrading Soil Bacteria," T.C. Hazen, assignors to the U.S. as represented by the U.S. DOE.
- Patent 5,384,048, "Bioremediation of Contaminated Groundwater," T.C. Hazen and C.B. Fliermans, assignors to the U.S. as represented by the U.S. DOE.
- Patent Submitted 2/94, "Contactor System for Phosphorus Addition to Support Gas Phase Environmental Bioremediation," B.B. Looney, T.C. Hazen, S. Pfiffner, and K. Lombard.

Related patents include:

- Patent 4,832,122, "In Situ Remediation System and Method for Contaminated Groundwater," J.C. Corey, B.B. Looney, and D.S. Kaback, assignors to the U.S. as represented by the U.S. DOE.
- Patent 5,186,255, "Flow Monitoring and Control System for Injection Wells," J.C. Corey, assignor to the U.S. as represented by the U.S. DOE.
- Patent 5,263,795, "In Situ Remediation System for Groundwater and Soils," J.C. Corey, D.S. Kaback, and B.B. Looney, assignors to the U.S. as represented by the U.S. DOE.
- Patent 4,660,639, "Removal of Volatile Contaminants from the Vadose Aone of Contaminated Ground," M.J. Visser and J.D. Malot, assignors to the Upjohn Company. WSRC paid a one-time license fee to the assignee for the use of the process with horizontal wells.
- Patent 5,006,250, "Pulsing of Electron Donor and Electron Acceptor for Enhanced Biotransformation of Chemicals, " P.V. Roberts, G.D. Hopkins, L. Semprini, P.L. McCarty, and D.M. McKay, assignors to the Board of Trustees of the Leland Stanford Junior University.

Licensing Information

- ISBR is commercially available through the WSRD Technology Transfer Office
- To date, 19 licenses have been applied for and six licenses have been granted.

Collaborators

Government

U.S. Department of Energy
- Savannah River Site
- Oak Ridge National Laboratory
- Hazardous Waste Remedial Actions Program
- Idaho National Engineering Laboratory
- Pacific Northwest Laboratory
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory

U.S. Environmental Protection Agency
U.S. Geological Survey
U.S. Air Force
U.S. Army Corps of Engineers
South Carolina Department of Health and Environmental Control

Academia

Stanford University
University of South Carolina
University of Illinois
University of Washington
Utah State University
Georgia State University
University of Minnesota
University of Cincinnati

Industry

Gas Research Institute
Radian Corp.
Eastman Christiensen
Westinghouse
E. I. duPont de Nemours Inc.
Michigan Biotech Institute
Envirex Inc.
Bechtel Inc.
Graves
O'Brien and Gere
Monitoring Testing Service
General Engineering Lab
Tren Fuels
South Carolina Electric and Gas Co.
Terra-Vac

APPENDIX E

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2. T. C. Hazen 1993. *Preliminary Technology Report for In Situ Bioremediation Demonstration (Methane Biostimulation) of the Savannah River Site Integrated Demonstration Project, DOE/OTD.* WSRC-TR-93-670. 39 pp. WSRC Information Services, Aiken, SC.

3. T. C. Hazen 1995. *Level 2 Summary Technology Report for In Situ Bioremediation Demonstration (Methane Biostimulation) of the Savannah River Site Integrated Demonstration Project, DOE/OTD.* in press.

4. D. S. Kaback, B. B. Looney, J. C. Corey, and L. M. Wright, III 1989. *Well Completion Report on Installation of Horizontal Wells for In Situ Remediation Tests.* WSRC-RP-89-784. Westinghouse Savannah River Company, Aiken, SC.

5. R. P. Saaty and S. R. Booth 1994. *In Situ Bioremediation: Cost Effectiveness of a Remediation Technology Field Test at the Savannah River Integrated Demonstration Site.* Los Alamos National Laboratory report No. LA-UR-94-1714.

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11. E.I.duPont de Nemours 1982. *Preliminary Technical Data Summary M-Area Groundwater Cleanup Facility, Savannah River Laboratory.*

12. A. L. Ramirez and W. D. Daily 1995. *Electrical Resistance Tomography During In Situ TCE Remediation at the Savannah River Site, Journal of Applied Geophysics.*

13. Martin Marietta Hazwrap in conjunction with Stone and Webster and CKY 1995. (prepared for the U.S. Department of Energy) *In Situ Air Stripping Using Horizontal Wells, Innovative Technology Summary Report.*

This report was prepared by:

Colorado Center
for
Environmental Management

999 18th Street, Suite 2750
Denver, Colorado 80202
Contact: Dawn Kaback
(303)297-0180 Ext. 111

in conjunction with:

Hazardous Waste Remedial
Actions Program
Martin Marietta Energy Systems

P.O. Box 2003
Oak Ridge, Tennessee 37831-7606
Randall Snipes/Scott Colburn
(615)435-3128/(615)435-3470

Assistance was provided by the

Westinghouse Savannah River Company
Savannah River Technology Center
Environmental Sciences Section

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

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

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

SIC Code:
Not Available

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.

Case Study Abstract

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).

SECTION I

SUMMARY

Technology Description

Lasagna™ is an integrated, in situ remediation technology being developed by an industrial consortium consisting of Monsanto, E. I. DuPont de Nemours & Co., Inc. (DuPont), and General Electric, with participation from the Department of Energy (DOE) Office of Environmental Management, Office of Science and Technology (EM-50), and the Environmental Protection Agency (EPA) Office of Research and Development (Figure 1).

Lasagna™ remediates soils and soil pore water contaminated with soluble organic compounds. Lasagna™ is especially suited to sites with low permeability soils where electroosmosis can move water faster and more uniformly than hydraulic methods, with very low power consumption. The process uses electrokinetics to move contaminants in soil pore water into treatment zones where the contaminants can be captured or decomposed. Initial focus is on trichloroethylene (TCE), a major contaminant at many DOE and industrial sites. Both vertical and horizontal configurations have been conceptualized, but fieldwork to date is more advanced for the vertical configuration. Major features of the technology are

- electrodes energized by direct current, which causes water and soluble contaminants to move into or through the treatment layers and also heats the soil;
- treatment zones containing reagents that decompose the soluble organic contaminants or adsorb contaminants for immobilization or subsequent removal and disposal; and
- a water management system that recycles the water that accumulates at the cathode (high pH) back to the anode (low pH) for acid-base neutralization. Alternatively, electrode polarity can be reversed periodically to reverse electroosmotic flow and neutralize pH.

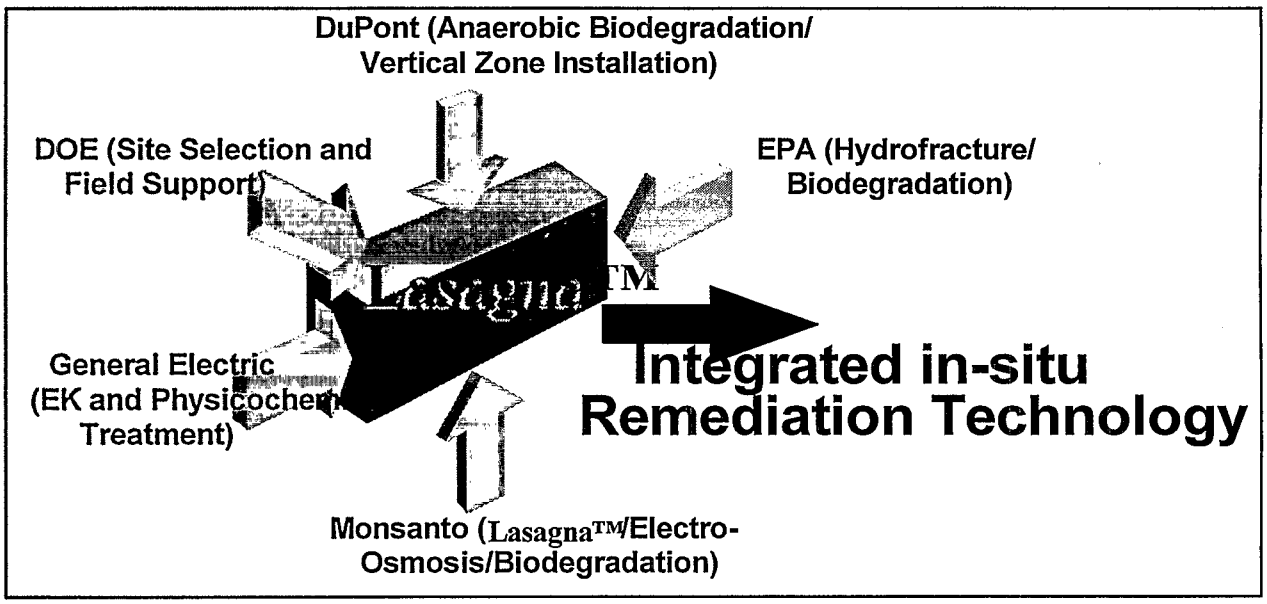


Figure 1. Major components of the Lasagna™ technology.

Technology Status

A proof-of-concept field demonstration was conducted at the Paducah Gaseous Diffusion Plant in Paducah, Kentucky.

U. S. Department of Energy
Paducah Gaseous Diffusion Plant (PGDP)
Cylinder Drop Test Area (SWMU 91)
Paducah, Kentucky
January 1995 through May 1995

The demonstration was sponsored by the DOE EM-50 Industrial Program through the Morgantown Energy Technology Center.

The PGDP site consists of a 4-ft layer of gravel and clay overlaying a 40-ft layer of sandy clay loam with interbedded sand layers. The clay soil had been contaminated with TCE at concentrations ranging from 1 ppb to 1760 ppm. Because of its very low organic content, the soil adsorbed very little TCE. The zone to be remediated measured 15-ft wide by 10-ft across and 15-ft deep, with average contamination of 83.2 ppm. The highest TCE concentrations (200–300 ppm) were found 12–16 ft below the surface. Steel panels were used as electrodes and the treatment zones consisted of wick drains containing granular activated carbon to adsorb the TCE. A plastic-wrapped shed was built above the test area, and a vent fan directed soil off-gas to an in-line filter for TCE capture.

Two patents covering the technology have been granted to Monsanto, and the term Lasagna™ has also been trademarked by Monsanto. Developing the technology so that it can be used with assurance for site remediation is the overall objective of the sponsoring consortium.

Key Results

- Soil samples taken throughout the test site before and after the test indicated an average removal efficiency of 98% for TCE, with some samples showing greater than 99% removal. TCE soil levels were reduced to an average concentration of 1.2 ppm.

- Flow rate by electroosmosis was 4 L/h, and three pore volumes of water (between adjacent treatment zones) were transported during the 4-month operating period.

- Dense, non-aqueous-phase liquid (DNAPL) locations were cleaned to 1-ppm levels except for a 15-ft deep sample that was reduced to 17.4 ppm (Note that because treatment zones were only 15-ft deep, diffusion from untreated deep zones may have contributed to the 17.4-ppm result.)

- A TCE mass balance at test conclusion accounted for about 50% of TCE. Differences may be a result of passive diffusion (5%), evaporation (5%), in situ degradation of TCE during the test, or incomplete extraction of TCE from the activated carbon prior to analysis. About 20% (12 of 64) of the wicks were sampled. Given the highly nonuniform TCE concentrations in the soil and the limited sampling, a mass balance of 50% is an excellent result.

- Based on the initial field tests, treatment costs for a typical 1–2-acre site with contamination to a depth of 40–50 ft were estimated to be about \$50–\$90/yd^3 of treated soil.

Phase II

A commercial-scale development demonstration (Phase IIa) is planned for the Paducah site in 1996, using iron filings in the treatment zones to dechlorinate the TCE in situ. The goal is to reduce soil contamination to 5.6 ppm or less in the 20 ft × 30 ft × 45-ft deep treatment zone. If successful, this will be followed by a

full-scale first application demonstration (Phase II) encompassing the entire contaminated region (105 ft × 60 ft × 45-ft deep), with treatment accomplished in 12 to 24 months.

Contacts

Technical

Sa V. Ho, Principal Investigator, Monsanto, (314) 694-5179
Steven C. Meyer, Project Manager, Phase IIA, Monsanto Enviro-Chem, (314) 275-5946
Joseph J. Salvo, General Electric, (518) 387-6123
Stephen H. Shoemaker, DuPont, (713) 586-2513

Management

Skip Chamberlain, DOE EM-50 Program Manager, (301) 903-7248
Jim Wright, DOE Plume Focus Area Manager, (803) 725-5608
Kelly Pearce, DOE Contract Representative, (304) 285-5424

Paducah Site Support

Myrna Redfield, DOE EM-40 Program Manager, (502) 441-6815
Fraser Johnstone, Lockheed Martin Energy Systems Project Manager, (502) 441-5077
Jay Clausen, Lockheed Martin Energy Systems Technical Manager, (502) 441-5070

SECTION 2

TECHNOLOGY DESCRIPTION

Vertical Proces Schematic

The Phase I field test of Lasagna™ had electrodes and treatment zones arranged as shown in Figure 2. DuPont and its subcontractor, Nilex Corporation, used an oversized mast and mandrel system to accommodate carbon-filled wick drains 18-in. wide by 2-in. thick. The wick drains were made by wrapping permeable geotextile fabric around a spacer material to create a conduit for groundwater flow. A wick was installed by inserting it through the steel emplacement mandrel that had been driven into the soil to the desired depth using a 10-ton vibratory hammer (Figure 3). A steel drive shoe placed over the leading edge of the hollow mandrel facilitated penetration to a depth about 15 ft below grade. Steel plate electrodes and geomembrane insulating panels were emplaced using the same mandrel.

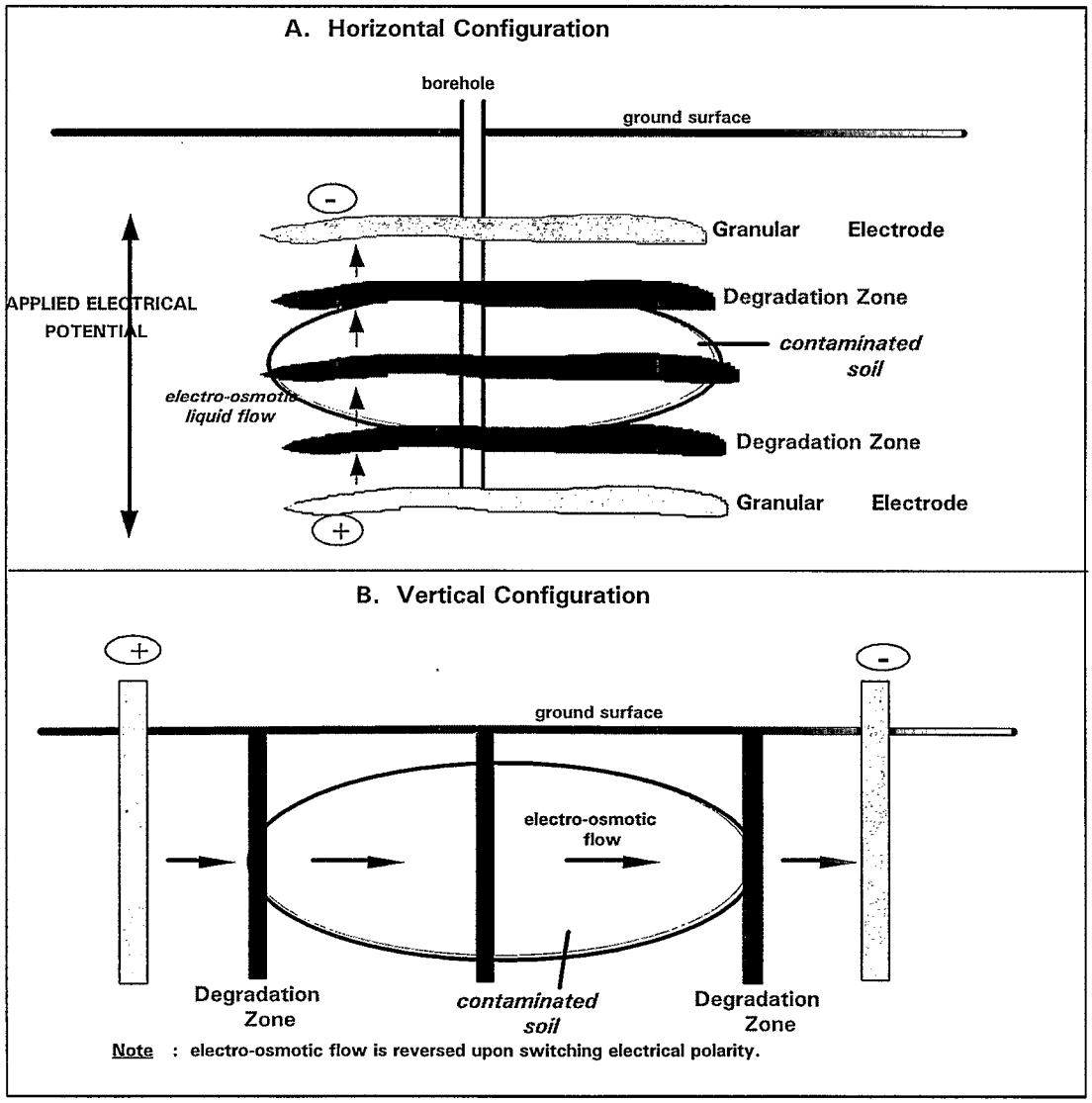


Figure 2. Horizontal and vertical Lasagna™ configurations.

Figure 3. Wicks being installed in hollow mandrel.

The treatment zones were installed with layers of soil 21-in. thick between each zone. Two wicks in each row contained a special sampling cassette that could be retrieved for TCE analysis during or after the experiment. A wick with a sampling cassette was also installed in the control zone at the west end of the unit, and this zone was isolated hydraulically by a surrounding wall of sheet piling.

Operating Characteristics of Phase I Demonstration

Initial power	138 volts, 41 amperes
Power after one month	105 volts, 40 amperes (remained stable at this level)
Electroosmotic flow rate	4–5 L/h
Initial soil temperature	15°C (at the 10-ft depth)
Temperature at test end	45.2°C (at the core, the hottest spot), 25–30°C (average soil temperature)

Electroosmotic conductivity, pH, conductivity trends, power requirements, temperature trends, and operational stability were predicted from laboratory and pilot-scale experiments and mathematical modeling and then confirmed in the field.

Phase IIa Treatment Plan

Phase IIa, scheduled to begin in June 1996, will modify the Phase I configuration by using zero-valent iron in the treatment zones to chemically reduce TCE to non-toxic end products—chloride ion, ethane, ethene, and other hydrocarbons. Laboratory studies by General Electric have shown that reduction rates are considerably enhanced by increasing temperature, making the soil heating that accompanies Lasagna™ an added benefit. Phase IIa will also test the ability of the technology to work at greater depth—45 ft—and will assess the use of wider spacing (up to 7 ft) between treatment zones to reduce costs.

Features of Phase IIa include the following:

- The test plot will be 20 ft × 30 ft × 45 ft deep.

- *Electrodes will be 30 vol % iron filings mixed with 70% carbon (coke) granules* (46 wt % iron and 54% coke on dry weight basis).
- Treatment zones 2-in. thick will be 8% by volume iron filings mixed with kaolin clay (35 wt-% iron and 65% clay on dry weight basis).
- The spacing array will be electrode <--7 ft-->|<--5 ft-->|<--2 ft-->|<--7 ft--> electrode (where | represents the treatment zone).
- The Nilex mandrel will be driven, filled with slurry (no wicks), and the mandrel removed.
- An in situ probe will periodically measure TCE concentration as treatment progresses.
- Phase IIa will operate 3–6 months to obtain data for a go/no-go decision on the complete Phase II. Target levels of 5.6 ppm TCE will not be reached in Phase IIa, and treatment of this zone would continue as part of Phase II.

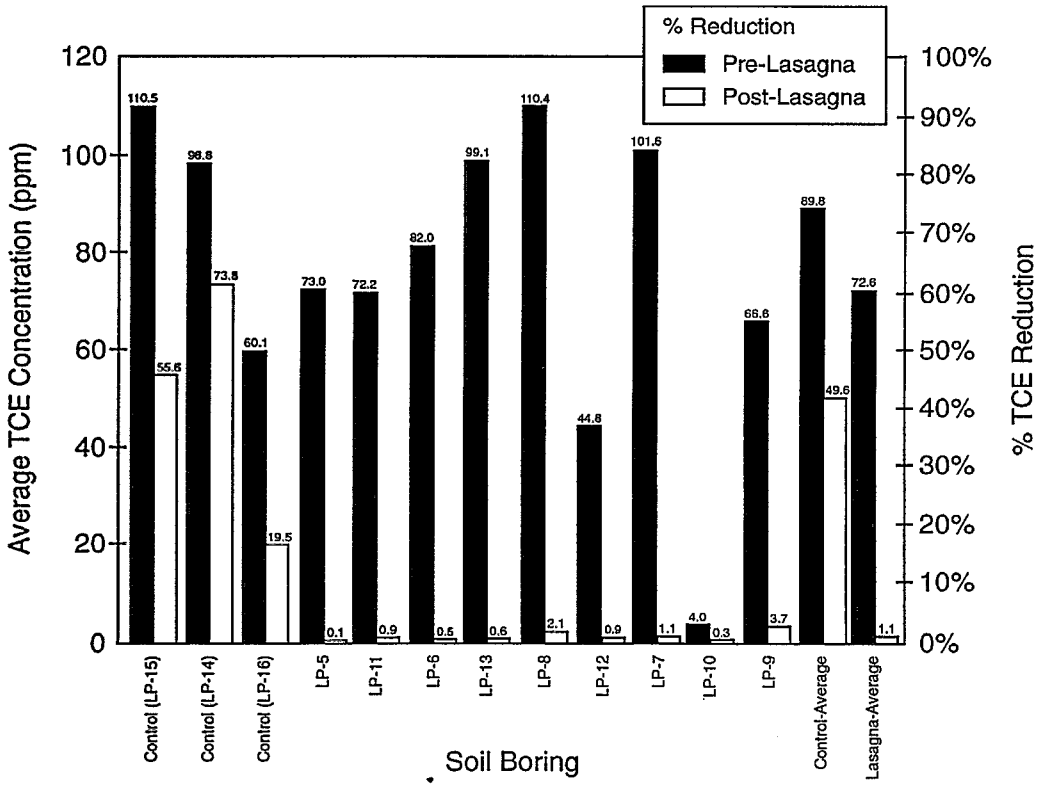
If the full Phase II treatment goes forward, a test array, about 105 ft × 60 ft × 45-ft deep will be used over a time span of 12 to 24 months. Cost objectives include a treatment cost of \$50–\$90/yd^3. Costs are expected to be lower if treatment time can be extended, thereby permitting use of fewer treatment zones (wider spacing) and/or less electrical power. More economical emplacement methods (e.g., jet grouting) could also reduce treatment costs.

Phase I Treatment Performance

This first field experiment demonstrated the following aspects of Lasagna™ technology.

- Electroosmosis can effectively transport groundwater contaminated by TCE to treatment zones where TCE is captured by adsorption on activated carbon.
- More than 98% of TCE can be removed from soil after just three pore volumes of water have been moved between adjacent treatment zones. Sampling of one wick showed that most TCE was captured after the first two pore volumes. Except at very low depths, little additional TCE was trapped by the third pore volume.
- The probable presence of residual DNAPL was indicated by pretest soil samples that showed TCE concentrations greater than 225 ppm. In these likely DNAPL locations, TCE levels were reduced to less than 1 ppm (except for a deep sample near the untreated zone that was reduced to 17.4 ppm), indicating that Lasagna™ technology could be effective for DNAPL TCE.

TCE removal from the soil is summarized in Figure 4 by results of the pretest and posttest analyses of soil cores. Very high and uniform removal of TCE from the treated soil between 4- and 15-ft depths is indicated. The location of the bore holes can be seen in the map of electrodes and treatment zones (Figure 5). Soil samples taken either outside of or deeper than the test zone (below 15 ft) showed substantial amounts of TCE present. This sharp contrast demonstrates the remarkable effectiveness of Lasagna™ treatment.



HAZ14279 6/14/96

Figure 4. Average trichloroethylene (TCE) concentrations pre- and post-Lasagna™.

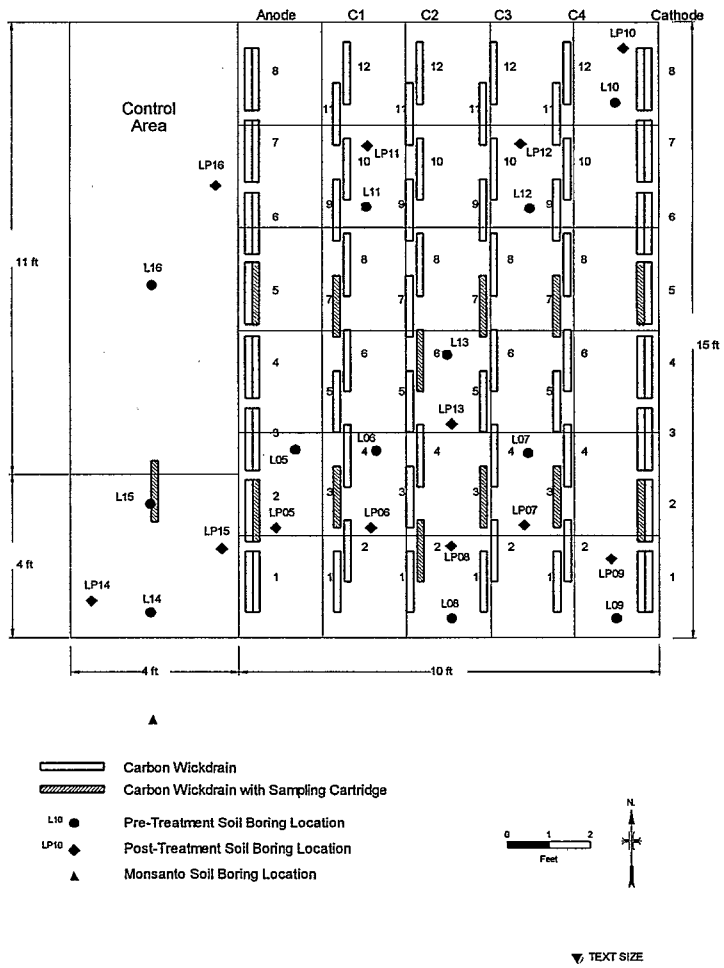


Figure 5. Locations of core samples from the Phase I Lasagna™ field experiment.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

Technology Applicability

- Low permeability soils with water-soluble contaminants (organics, inorganics, or mixed wastes) could be remediated using Lasagna™ technology.
- Field experiments at PGDP are staged to quantify performance variables and determine cost effectiveness for in situ TCE remediation.
- Phase I results indicate that electroosmosis can remove residual DNAPL TCE from soil, with concentrations reduced to approximately 1 ppm after 4 months of treatment.
- Phase II tests will evaluate in situ degradation of TCE by reaction with zero-valent iron and the compatibility of this process with electroosmotic transport.

Competing Technologies

For contaminants in low permeability soils, removal or destruction of the contaminants is generally made difficult by the slow, nonuniform transport of water or air through the soil. This limits the effectiveness of other in situ methods such as pump and treat, vapor extraction, or bioremediation.

A number of soil heating/vapor extraction technologies have been demonstrated at DOE sites (some on soils of low permeability), with treatment cost estimates ranging from \$65/yd^3 (DOE 1995a), to \$88/yd^3 (DOE 1995b), to \$123/yd^3 (Dev and Phelan 1996). (The referenced reports should be consulted for details.)

Barriers that prevent the further spread of contaminants may be effective remedies in cases where drinking water supplies are not endangered by the contamination. However, once a plume is identified and characterized, public pressure often demands that the offending source be removed or destroyed. Also, barrier technology for plumes has not yet been shown to be feasible, effective, or cost-efficient. (Freeze and McWhorter)

Use of treatment zones for in situ destruction of contaminants gives Lasagna™ a competitive advantage over other electrokinetic methods that extract contaminants for aboveground treatment or disposal. Because treatment zones eliminate the need for aboveground waste handling, and are presumably cheaper to make and install than electrodes, their use imparts cost advantages.

In situ chemical oxidation with reagents such as potassium permanganate or hydrogen peroxide has been proposed as a way of degrading DNAPLs in situ, with reagent delivery accomplished by soil mixing or fracturing in conjunction with oxidant solution injection. Cost estimates of \$130 to \$200/m^3 have been made for the technology based on limited full-scale data (TCE treated with hydrogen peroxide at 80% removal efficiency) (Gates, Korte, and Siegrist). A recently issued report summarizes the results of the demonstration of in situ soil mixing for volatile organic contaminant remediation that was conducted at the Portsmouth, Ohio, DOE site (DOE 1996).

SECTION 5

COST

Introduction

DuPont has completed an engineering evaluation and cost analysis of the vertically configured Lasagna™ treatment process using a cost optimization model. Input parameters included soil properties, depth of contamination, cost for emplacing electrodes and treatment zones, required purge water volume, cleanup time, and cost of electrical power. For TCE contamination in clay, costs are estimated to range from \$40 to \$90/yd^3 of soil for a 1-acre site.

The cost-optimized electrode spacing for electroosmosis is 3–6 m for most soils. This allows cleanup within a reasonable time (less than 5 years) while avoiding soil overheating. Electrode construction is a major factor in overall application cost—generally 20 to 40%. Lasagna™ reduces the cleanup time and power input by inserting treatment zones between the electrodes. The ability to emplace treatment zones and electrodes in relatively close spacing and at reasonable cost is critical to the cost-effectiveness of the technology.

The technology implementation cost for Lasagna™ as conducted in the Phase I test (steel plate electrode with wick drains and carbon-filled treatment zone) is estimated at \$80–\$90/yd^3 for remediation in 1 year, \$50–\$60/yd^3 if 3 years are allowed for remediation. Comparable estimates for the Phase II mode of operation are \$60–\$70 (1 year) and \$40–\$50 (3 years). Deeper contamination, although involving more technically challenging emplacement, costs less because of the larger volumes remediated per area of electrode.

A hypothetical case wherein mass-produced, prefabricated materials were emplaced by the mandrel technology was also considered by DuPont. This best possible case lowered implementation costs to \$30–\$40 (1-year case) and \$20–\$30 (3-year case), depending on the depth of contamination. Wide adoption of the technology would presumably be needed to stimulate the development of these new materials.

In all of the above cases, only the direct costs associated with technology application are included. Additional variable costs related to licensing fees, site costs imposed because of regulations, analytical costs, etc. are not included.

Cost Savings Versus Alternative Technologies

DuPont has benchmarked a number of in situ technologies over the last 3 years. These include

- in situ treatment zones using iron filings for dehalogenation of chlorinated solvents,
- pump and treat of contaminated groundwater,
- in situ aerobic biological dechlorination, and
- surfactant flushing.

Costs for these technologies, some of which require more than 30 years to remediate a site, are between \$25 and \$75/yd^3. Lasagna™ is within the range of these competing technologies with an implementation cost (over 3 years) of about \$50/yd^3, using the mandrel/tremie-tube method of emplacement as proposed for Phase II.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

Communication with regulators should be established early in the development process for new remediation technologies. For the PGDP demonstrations of Lasagna™, early contact with EPA and state of Kentucky regulators led to determinations that

- no air permits were needed (negligible amounts of TCE would be vaporized by the electrical heating of soil);
- no underground injection permit was needed (water would be recycled from cathode to anode, not injected at depth);
- the soil cleanup standard of 5.6 ppm achieved the maximum contaminant level (5 ppb in water) for TCE at the point of exposure;
- the PGDP security fence could be established as the point of exposure for consumption, thereby serving as the basis for the soil cleanup standard; and
- the demonstration would be granted a categorical exclusion under the National Environmental Policy Act (no environmental impact).

Safety, Risks, Benefits, and Community Reaction

The intermediate degradation products of TCE reduction should be monitored as well as TCE. Water cleanup targets for *cis*-dichloroethylene (70 ppb) and vinyl chloride (2 ppb) suggest that vinyl chloride will be the more significant health risk concern.

No permit was needed for the electrical installation, but site inspection by a qualified electrical engineer and lock-out/tag-out training for site personnel were required

SECTION 7

LESSONS LEARNED

Design Issues

- Phase I results indicate that electroosmosis can flush TCE from clay soil with the passage of two or three pore volumes of water between adjacent treatment zones. More flushing may be required when greater amounts of DNAPL are present.
- Partial plugging of the cathode siphon tubes during the first month of Phase I testing caused water to overflow the cathode wicks. Pinched tubes can be prevented by better design or more robust tubing.

Implementation Considerations

- Iron corrosion was the dominant anode reaction for the first 3 months of power application, but water electrolysis apparently occurred in the 4th month, lowering the pH near the anode to 2–3. Electrode polarity reversal may be a desirable option to mitigate this effect for long-term power applications.

Technology Limitations/Needs for Future Development

- Phase II testing will address a number of design and operational issues, including treatment zone spacing, effectiveness of zero-valent iron degradation of TCE when used in conjunction with electroosmosis, and emplacement of vertical granular electrodes and treatment zones to 45-ft depths by the mandrel/tremie-tube method. Greater amounts of DNAPL TCE are also anticipated, possibly requiring more electroosmotic flushing than was used in Phase I.
- Lasagna™ is potentially capable of treating multiple contaminants in soil, but treatment chemistry and procedures will have to be developed to assure compatibility of the treatment processes for individual contaminants.
- Hydraulic fracturing and slurry emplacement of horizontal electrodes and treatment zones offer promise for Lasagna™ treatment of deep zones of contamination, but issues of good electrical contact to electrodes and trapping of gases generated by electrolysis need to be resolved by the technology developers, EPA and the University of Cincinnati.
- Bioremediation in Lasagna™ treatment zones is an option that has been demonstrated in the laboratory by Monsanto and is now being evaluated by EPA, Monsanto, and others for field implementation. This will require further development.

Future Technology Selection Considerations

- Lasagna™ is a modular technology, and plans to remediate the entire PGDP Cylinder Drop Test Area (SWMU 91) assume that the Phase IIa configuration can be used in six adjacent, like-sized areas that would be treated concurrently in Phase II.
- Site evaluations and negotiations are proceeding with Department of Defense sites interested in collaborating with the consortium on a demonstration of the horizontal configuration of Lasagna™, probably using bioremediation in the treatment zones.
- Improvements in treatment zone emplacement technology may be possible through the use of cheaper materials with the mandrel/tremie-tube technology or through the use of jet grouting. DuPont will explore these options as part of the Phase II development work.

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This report was prepared by:

S.A.I.C.
555 Quince Orchard Rd
Suite 500
Gaithersburg, Maryland 20878
Contact: Dennis Kelsh
(301) 924-6130

under contract and in conjunction with:

HAZARDOUS WASTE REMEDIAL ACTIONS PROGRAM
Environmental Management and Enrichment Facilities
Oak Ridge, Tennessee 37831-7606
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400
Contact: Scott Colburn
(423) 435-3470

and in conjunction with:

The Colorado Center for Environmental Management
999 18th Street
Suite 2750
Denver, Colorado 80202
Contact: Dawn Kaback
(303) 297-0180 ext. 111

VITRIFICATION CASE STUDIES

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.

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

Case Study Abstract

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.

COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for an in situ vitrification (ISV) treatment application at the Parsons Chemical/ETM Enterprises Superfund Site (Parsons) in Grand Ledge, Michigan. 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 yds^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.

Treatment performance data for this application include SITE program results for surface soil samples and stack gas emissions, results for "typical" stack gas emissions provided by the vendor, and confirmation coring analytical results.

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 areas with potential residual contamination. Samples were collected in the vitrified material and in the containment soil approximately 3 to 4 feet beneath the bottom of the glassified material. Vitrified material was analyzed for mercury and pesticides using a TCLP, while containment soil was analyzed for volatiles and semivolatiles using a total waste analysis. 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.

In addition, the SITE program results and results for typical stack gas emissions show that this application met the soil cleanup standards and off-gas emission ARARs for this application. The stack gas emissions for chlordane and 4,4'-DDT were several orders of magnitude lower than the ARARs. A volume reduction of approximately 30% for the test soil was achieved in this application, based on the results from analyses of soil dry density.

The cleanup contractor's cost ceiling for the ISV treatment application at Parson's was $1,763,000, including $800,000 for vitrification, which corresponds to $270 per cubic yard of soil treated. The estimated before-treatment costs for this application of $800,000 were high because of the need to excavate and stage the wastes prior to treatment.

SITE IDENTIFYING INFORMATION

Identifying Information:

Parsons Chemical/ETM Enterprises
Grand Ledge, Michigan
CERCLIS # MID980476907
Action Memorandum Date: 21 September 1990

Treatment Application:

Type of Action: Removal
Treatability Study associated with application? Information not available at this time
EPA SITE Demonstration Program test associated with application? Yes (see Reference 41)
Period of operation: 5/93 - 5/94
Quantity of material treated during application: 3,000 cubic yards of contaminated soils and sediments (5,400 tons) [41]

SITE IDENTIFYING INFORMATION (CONT.)

Background (cont.)

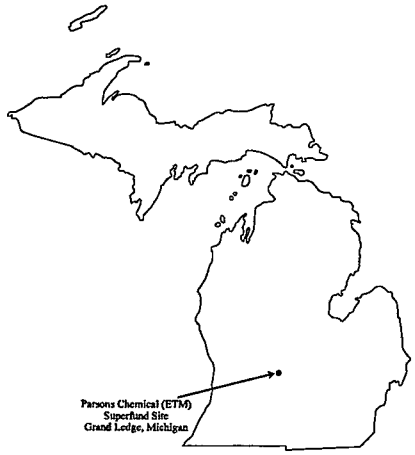

Figure 1. Site Location

Background

Historical Activity that Generated Contamination at the Site: Mixing, manufacturing, and packaging of agricultural chemicals

Corresponding SIC Code: 2879 (Agricultural Chemicals - not elsewhere classified)

Waste Management Practice that Contributed to Contamination: Manufacturing process

Site History: The Parsons site, located near Grand Ledge, Michigan, as shown in Figure 1, is a former agricultural chemicals mixing, manufacturing, and packaging facility. Materials handled during Parsons' operation included pesticides, herbicides, solvents, and mercury-based compounds. Parsons occupied the property from April 1945 until 1979. The site is presently owned by ETM Enterprises, a manufacturer of fiberglass. [2]

Wash water from Parsons' operations was discharged through floor drains to a catch basin leading to the county drain system. The county drain system flows to an unnamed creek which ultimately empties into the Grand River. In 1979 and 1980 the Michigan Department of Natural Resources (MDNR) collected sediment samples from the unnamed creek and a ditch located on the north boundary of the site. Elevated levels of lead, mercury, arsenic, and pesticides, including dichloro-diphenyl-trichloroethane (DDT) and chlordane were detected in the samples. A hydrogeological investigation, performed during 1980, identified a septic tank and leach field system as the source of contamination. The septic tank and leach field were subsequently excavated in 1983.

Parsons was included in the Tier 3 dioxin screening under the National Dioxin Study conducted in 1984. 2,3,7,8-Tetrachlorodibenzo-p-dioxins (TCDD) was detected in the ditch sediments at the site at a concentration of 1.13 ppb at the surface and 0.56 ppb at a depth of 18 inches below the surface. [2, 27]

Regulatory Context: An action memorandum, dated September 21, 1990, was approved by EPA to conduct a removal action at the Parsons site. The removal actions proposed for the site included [2]:

- Developing and implementing a site safety plan and security measures;
- Implementing a site air monitoring program;
- Characterizing, excavating, and staging all contaminated soils to facilitate the ISV process;
- Conducting a study to confirm that contaminated soils have been removed to acceptable levels;
- Treating on-site waste in a staging area utilizing ISV; and
- Completing site restoration in excavation and treatment areas.

Cleanup requirements for the site were established for near-surface vitrified materials and air emissions, as discussed below under cleanup goals and standards. [25]

Remedy Selection: Several options were considered for cleanup of the Parsons site, including ISV, incineration, and stabilization. ISV was selected as the remedy because this technology was determined to be capable of reducing volume by 20 to 30%, decreasing the toxicity to near zero, and permanently immobilizing the hazardous substances on the site. ISV was also identified as less expensive than on-site incineration. [2]

SITE IDENTIFYING INFORMATION (CONT.)

Site Logistics/Contacts

Site Management: Fund Lead
Oversight: EPA
On-Scene Coordinator:
Len Zintak
U.S. EPA Region 5
77 West Jackson Boulevard
Chicago, IL 60604-3507
(312) 886-4246

Treatment System Vendor:
James E. Hansen
Geosafe Corporation
2950 George Washington Way
Richland, WA 99352
(509) 375-0710

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix processed through the treatment system: Soil (in situ)

Contaminant Characterization

Primary contaminant groups: Pesticides, heavy metals, and dioxin

The maximum concentrations measured in the soil at Parsons for specific contaminants are shown in Table 1. [27]

Table 1. Maximum Contaminant Concentrations in Soil [27]

Contaminant	Maximum Concentrations in Soil (µg/kg)
g-BHC (Lindane)	78000
Bis(2-ethylhexyl) phthalate	28000
Butyl benzyl phthalate	6400
Chlordane	89000
4,4'-DDD	48000
4,4'-DDE	37000
4,4'-DDT	340000
Dieldrin	87000
Endosulfan sulfate	1300
Fluoranthene	1200
Hexachlorobenzene	2600
Mercury	34000
Methoxychlor	850
2-Methylnaphthalene	1100
Phenanthrene	990
Pyrene	1400
2,3,7,8-Tetrachloro-dibenzo-p-dioxin	1.13
Zinc	150000

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Cost or Performance

The major matrix characteristics affecting cost or performance for this technology and their measured values are presented in Table 2.

Table 2. Matrix Characteristics [4, 11]

Parameter	Value	Measurement Procedure
Soil Classification	Silty Clay	Not Available
Clay Content and/or Particle Size Distribution	Not Available	-
Moisture Content	Not Available	-
Soil Dry Density	1.48 tons/yd³	Not Available

The soil at Parsons was reported to be difficult to work with under very wet and very dry conditions. Wet conditions caused the soil to become highly fluid and exhibit a noticeable sulfurous odor. Under dry conditions, the soil became concrete-like. The soil also had a very high moisture content, and the soil moisture contained a high level of dissolved solids. [25]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

In Situ Vitrification

Supplemental Treatment Technology:

Post-treatment (air) using quench, scrubber, and thermal oxidizer

In Situ Vitrification System Description and Operation

In situ vitrification (ISV) is an immobilization technology designed to treat media contaminated with organic, inorganic, and radioactive contaminants. The primary residual generated by ISV is the vitrified soil product. Secondary residuals generated by ISV include air emissions, scrubber liquor, carbon filters, and used hood panels. [41]

System Description

The ISV system used at Parsons consisted of 9 melt cells, as shown in Figure 2, an air emissions control system, and associated equipment. The melt cells were installed in a 16-foot deep treatment trench; each cell was 26 feet by 26 feet square. The trench was designed with a cobble wall and drain system to direct perched water that flowed into the site around the melt cells. [25]

The air emissions control system used at Parsons consisted of an off-gas collection hood, a quencher, a water scrubber, and a thermal oxidizer. The thermal oxidizer was added midway through the project to help control stack gas odors. [25]

Associated equipment used at the Parsons site included electrical transformers, capacitor tanks, natural gas metering equipment, and thermocouples and other monitoring equipment. [13]

The following technology description is an excerpt from the SITE Technology Capsule [41]:

"The ISV Technology [used at Parsons] operates by means of four graphite electrodes, arranged in a square and inserted a short distance into the soil to be treated. A schematic of the Geosafe process is presented in Figure 3.

TREATMENT SYSTEM DESCRIPTION (CONT.)

In Situ Vitrification System Description and Operation (cont.)

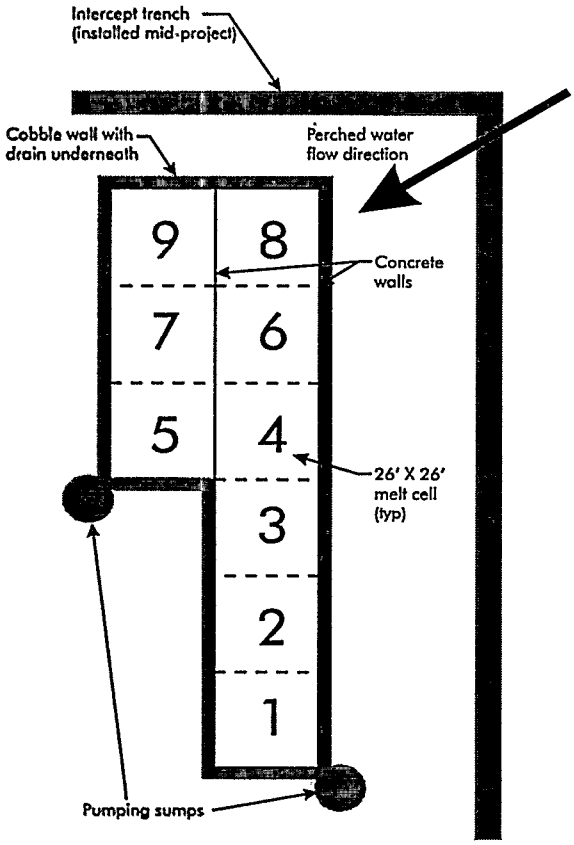

Figure 2. Plan View of Treatment Cells [25]

ISV uses electrical current to heat (melt) and vitrify the treatment material in place. A pattern of electrically conductive graphite containing glass frit is placed on the soil in paths between the electrodes. When power is fed to the electrodes, the graphite and glass frit conducts the current through the soil, heating the surrounding area and melting directly adjacent soil.

Molten soils are electrically conductive and can continue to carry the current which heats and melts soil downward and outward. The electrodes are allowed to progress down into the soil as it becomes molten, continuing the melting process to the desired treatment depth. One setting of four electrodes is referred to as a "melt." Performance of each melt occurs at an average rate of approximately three to four tons/hr.

When all of the soil within a treatment setting becomes molten, the power to the electrodes is discontinued and the molten mass begins to cool. The electrodes are cut near the surface and allowed to settle into the molten soil to become part of the melt. Inorganic contaminants in the soil are generally incorporated into the molten soil which solidifies into a monolithic vitrified mass similar in characteristics to volcanic obsidian. The vitrified soil is dense and hard, and significantly reduces the possibility of leaching from the mass over the long term.

The organic contaminants in the soil undergoing treatment are pyrolyzed (heated to decomposition temperature without oxygen) and are generally reduced to simple gases. The gases move to the surface through the dry zone immediately adjacent to the melt, and through the melt itself. Gases at the surface are collected under a stainless steel hood placed over the treatment area and then treated in an off-gas treatment system. The off-gas treatment system comprises a quencher, a scrubber, a demister, high efficiency particulate air (HEPA) filters, and activated carbon adsorption to process the off-gas before releasing the cleaned gas through a stack. A thermal oxidizer can be used following the off-gas treatment system to polish the off-gas before release to the atmosphere. A thermal oxidizer was utilized during the SITE Demonstration at the Parsons site."

System Operation

Eight melts were required to vitrify the soil in the nine melt cells. These melts were performed at the Parsons site from June 1993 to May 1994. As shown on Table 3, these melts ranged in duration from 10 to 19.5 days, and consumed from 559,200 to 1,100,000 kilowatt-hours of electricity per melt. The melts required approximately one year to be sufficiently cooled to sample. [10-24] Confirmation borings were collected in April 1995 (see discussion under "Treatment Performance Data").

TREATMENT SYSTEM DESCRIPTION (CONT.)

In Situ Vitrification System Description and Operation (cont.)

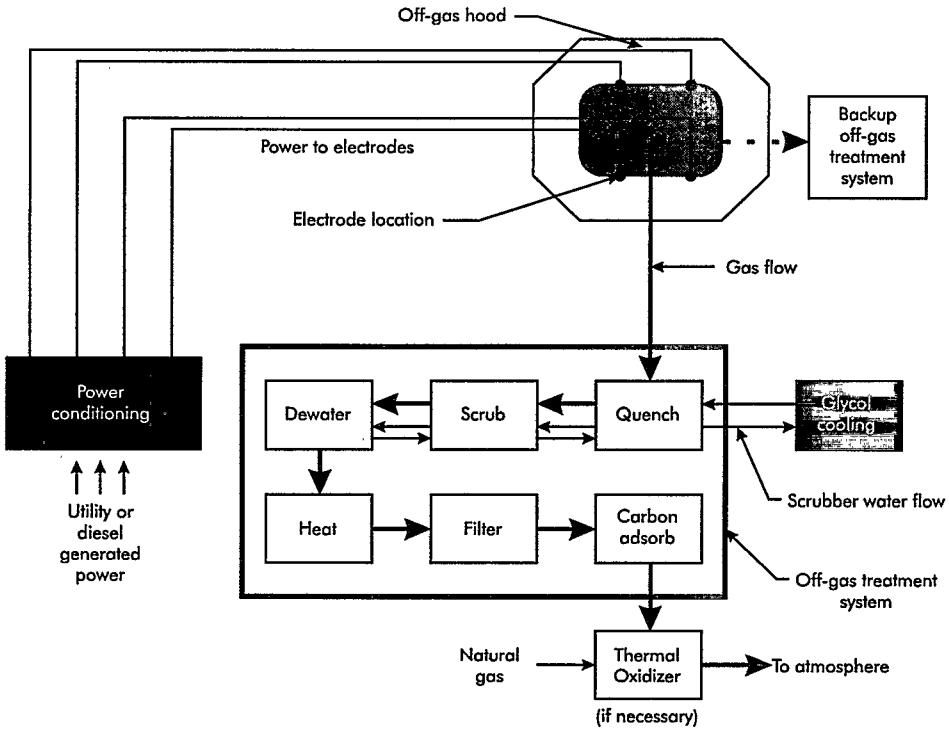

Figure 3. Geosafe In Situ Vitrification Process [41]

Table 3. Operational Data [10-24]

Melt #	Cell #	Soil Treated* (cubic yards)	Duration of Melt (days)	Power Consumed (kilowatt-hours)	Natural Gas Consumed in Thermal Oxidizer (cubic feet)
1	1 and part of 2	300	19.5	1,100,000	N/A
2	2 and part of 3	330	14	934,000	N/A
3	part of 3, 4 and 7	621	16.7	1,018,000	N/A
4	7 and part of 4, 5, and 8	672	16	996,000	N/A
5	5 and part of 4, 6, and 8	655	16	1,084,800	4,100,000
6**	8 and part of 5, 7, and 9	377	10	559,200	Not Available
7	6 and part of 5, 8, and 9	575	14	836,985	Not Available
8	9 and part of 6 and 8	426	11.5	640,800	Not Available

N/A - Not applicable; thermal oxidizer not installed until after Melt #4 complete.
**Quantities shown are Geosafe estimates of contaminated and clean soil treated; total quantity of soil treated greater than 3,000 cubic yards of contaminated soil because treatment of clean soil occurred in this application.*
***SITE Demonstration Program test.*

TREATMENT SYSTEM DESCRIPTION (CONT.)

In Situ Vitrification System Description and Operation (cont.)

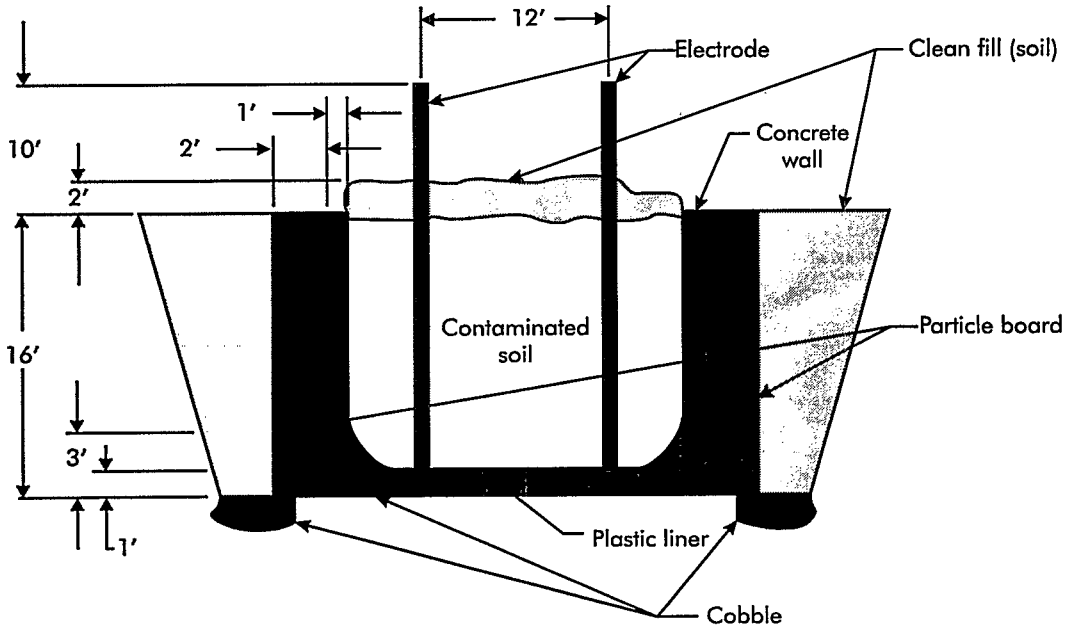

Figure 4. Side View of Typical ISV Treatment Cell [41]

The SITE Technology Capsule provides the following description of system operation at Parsons [41]:

"At the Parsons site, the original soil contamination was relatively shallow, five feet or less, and located in three main areas. To increase the economic viability of treatment at this site, the contaminated soil was excavated and consolidated into a series of nine treatment cells. The cell walls were built using concrete, cobble, and particle board as shown in Figure 4. The cells were constructed by trenching an area of the site, installing particle board and concrete forms, and pouring concrete into the forms to create the nine cell settings. A one-foot layer of cobble was placed in the bottom of each cell, and approximately two feet of cobble was used to surround the exterior of the cell forms. The use of cobble at the sides was intended as a means to retard melting out into adjacent clean soil. The bottom cobble was used to provide a drainage pathway for water that was known to be present on-site; the resultant flow of water was directed to a drainage trench. After construction, the cells were filled with contaminated soil from the site, and topped with a layer of clean soil.

During the treatment of the first few cells, problems with the cell design were observed. The intense heat that was melting the soil was also thermally decomposing the particle board forms. Analysis of water samples collected from the diversion system surrounding the cells identified volatiles (benzene), phenolics, and epoxies that were released by this decomposition. The cobble outside of the cells created porous paths in the vicinity of treatment, thereby increasing the likelihood of vapors escaping the area outside the hood and causing irregular melt shapes.

Geosafe responded by excavating the area outside of the remaining treatment cells and removing the particle board forms. A refractory ceramic material with insulating and reflective properties was placed adjacent to the exterior of the concrete cell walls. This helped to control the melt shape, limit fugitive vapor emissions, and restrict the melt energy inside the cell boundaries. . . . . It should be noted that the use of cobble in treatment cell construction was unique to the Parsons site where the configuration and flow of the on-site groundwater dictated its application.

TREATMENT SYSTEM DESCRIPTION (CONT.)

In Situ Vitrification System Description and Operation (cont.)

Utility requirements for this technology include electricity, natural gas (if a thermal oxidizer is used), and water. As expected, electricity is a major consideration when implementing ISV. Total power to the electrodes during treatment is approximately three MW; the voltage applied to each of the two phases during steady state processing averages around 600 volts while the current for each phase averages approximately 2,500 amps."

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameters affecting cost or performance for this technology and the values measured for each are presented in Table 4.

Table 4. Operating Parameters [10-24]

Parameter	Value	Measurement Procedure
Soil Treated	300-672 cubic yards per melt	Vendor estimate
Melt Duration	10-19.5 days per melt	-
Power Consumption	559,200-1,100,000 kWh/melt	-

Timeline

A timeline for this application is shown in Table 5.

Table 5. Timeline [1, 10-26]

Start Date	End Date	Activity
3/89	-	Parsons added to NPL
9/90	-	Action memorandum signed
10/90	4/91	Site preparation work completed (excavation and staging of 3,000 cubic yards into ISV treatment cells)
3/91	-	Operational acceptance test terminated due to fire
5/93	6/93	Mobilization of equipment and personnel to site
6/93	9/93	ISV treatment conducted
9/93	11/93	ISV treatment suspended for 9 weeks pending discussions about scrubber solution disposition, stack gas odors, groundwater disposition, and melt shape
11/93	12/93	ISV treatment continued
1/94	-	Thermal oxidizer installed to control stack gas odors
2/94	5/94	ISV treatment continued
3/94	4/94	SITE Demonstration Program test (Melt #6)
5/94	date not provided	Decontamination, dismantling, and demobilization conducted
4/95	-	Confirmation corings collected

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

Cleanup requirements were established for soils remaining on site and for off-gasses from the ISV unit, as shown below in Table 6.

Table 6. Cleanup Requirements [25, 28]

Contaminant	Soil CleanupStandards (mg/kg)	Off-Gas State ARAR (lbs/hr)
Chlordane	1	25
4,4'-DDT	4	0.01
Dieldrin	0.08	0.00028
Mercury	12	0.00059

Treatment Performance Data

Treatment performance data for this application include SITE Program data for vitrified soil, analyses of stack gas emissions, and confirmation corings. Table 7 shows selected results from the SITE Demonstration for vitrified soil and stack emissions in melt #6. During the SITE Demonstration, three samples of vitrified soil were collected from the surface of Cell 8, and analyzed for pesticides and metals (total and TCLP). Stack gas emissions were also tested for total hydrocarbons (THC) and carbon monoxide (CO). During the SITE Demonstration, THC and CO were each measured at less than 10 ppmv. [41]

Table 8 shows typical stack gas emission performance data as reported by the vendor.

Table 7. Selected Results from the SITE Demonstration Program for Melt #6 [41]

	Before-Treatment Soil		After-Treatment Surface Soil		Stack Gas Emissions	
Contaminant	Total (µg/kg)	TCLP (µg/L)	Total (µg/kg)	TCLP (µg/L)	Concentration (µg/m³)	Mass (lbs/hr)
Chlordane	<80	<0.5	<80	<0.5	<1.38	<0.000011
4,4'-DDT	2,400-23,100	0.12-0.171	<16	<0.1	<0.28	<0.0000022
Dieldrin	1,210-8,330	6.5-10.2	<16	<0.1	<0.28	<0.0000022
Arsenic	8,380-10,100	NA	717-5,490	<4-30.5	<0.269	<0.000001293
Chromium	37,400-47,600	NA	12,500-14,600	<10-17.1	2.081-3.718	0.0000148-0.0000267
Lead	<50,000	NA	<5,000-21,00	<50-4,290	<3.891	<0.0000282
Mercury	2,220-4,760	NA	<40	<0.2-0.23	12.9-17.7	0.0000989-0.000125

NA - Not analyzed.

Table 8. Typical Stack Gas Emissions [25]

Contaminant	State ARAR (lbs/hr)	Stack Gas Emission (lbs/hr)
Chlordane	25	<0.00000011
4,4'-DDT	0.01	<0.000022
Dieldrin	0.00028	<0.000022
Mercury	0.00059	0.00012

TREATMENT SYSTEM PERFORMANCE

Treatment Performance Data

Confirmation Corings [42]

Confirmation corings were performed in April 1995 after the melt had cooled for approximately one year. Three confirmation corings were drilled at the site, consisting of the following: Drill Hole (DH) 101, positioned on melt 1, cell 1; DH 102, positioned on melt 3, between cells 3 and 4; and DH 103, positioned between melts 5 and 7, cell 5. These corings locations were selected to represent the areas with potential residual contamination. Areas were selected based on an evaluation of areas which had 1) failed to burn out bottom thermocouples as planned, and 2) showed inadequate melt depth, as indicated by electrode depth below grade level.

Corings were performed as follows: the first 5 feet of overburden in each location was drilled using a 4 1/4-inch diameter hollow stem auger. The vitrified material beneath the overburden (the upper portion of vitrified material is referred to as the vesicular region) was first scored using a 2 1/2-inch diameter tricone rotary bit, and then drilled using a 2 3/4-inch diameter diamond-impregnated #10 Longyear drill bits. Material beneath the vitrified material, such as the lower vesicular region, underlying cobble, and underlying soil, was drilled using a 3-inch diameter split spoon sampler with a cable tool driver.

Core sections were collected from several depths within each of the three coreholes and analyzed by EPA's and Geosafe's laboratories. Table 9 summarizes the depths that were sampled for each corehole, the type of material sampled (e.g., glass, soil), and the corresponding analytical results for the samples analyzed by Geosafe's laboratory. No data are contained in the available references on the analytical results for the samples analyzed by EPA's laboratory.

*Table 9. Analytical Results for Confirmation Coring Samples Collected by Geosafe [42]**

Drill Hole Identifier	Sample Depth (FT)	Sampled Material	Mercury and Pesticides**	Volatiles	Semivolatiles
DH-101	10	Glass	ND	NA	NA
DH-101	14	Glass	ND	NA	NA
DH-101	18	Containment Soil	NA	ND	ND
DH-101	19	Containment Soil	NA	ND	ND
DH-101	10.5	Glass	ND	NA	NA
DH-102	13.5	Glass	ND	NA	NA
DH-102	17	Containment Soil	NA	NA	NA
DH-103	9	Glass	ND	NA	NA
DH-103	12	Glass	ND	NA	NA
DH-103	15	Containment Soil	NA	ND	ND
DH-103	16	Contaniment Soil	NA	ND	ND

ND = None Detected (detection limit not provided)
NA = Not Analyzed
**Specific pesticides, volatiles, and non-volatiles analyzed for this application were not identified in the available references.*
***Results shown for mercury and pesticides are based on TCLP analysis.*

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment

The treatment performance data in Table 7 shows that the surface soil samples and stack gas emissions measured during the SITE Demonstration met the soil cleanup standards and off-gas State ARARs for this application. In addition, the typical stack gas emission data provided by the vendor, as shown in Table 8, show compliance with the State ARARs. The data in Table 8 show that the stack gas emissions for chlordane and 4,4'-DDT were several orders of magnitude lower than the ARARs.

The data in Table 7 show a reduction in total waste analysis concentrations from levels as high as 23,100 μg/kg to levels less than 11 μg/kg for chlordane, 4,4'-DDT, and dieldrin in surface soil samples. Concentrations of metals in a TCLP extract are shown to be reduced from as high as 21,000 μg/L to levels less than 5,000 μg/L.

Additional data from the SITE Demonstration show a volume reduction of approximately 30% for the test soil, based on the results from analyses of soil dry density.

The confirmation coring sampling results shown in Table 9 indicate that the vitrified material in all three drill holes had mercury and pesticide concentrations below detection limits, as measured using a TCLP analysis, and therefore that the vitrified material met the cleanup goals for this application. Note that the available references do not state the specific pesticide constituents analyzed or provide the detection limits achieved in this application. Also as shown in Table 9, 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. Again the specific constituents analyzed and the detection limits achieved in this application were not provided in the available references. The containment soil samples were collected approximately three to four feet beneath the bottom of the vitrified material in each of the three drill holes.

Performance Data Completeness

Data are available to characterize the results of the ISV application at Parsons, including data on stack gas emissions, surface soil samples collected during the SITE Demonstration, and confirmation boring sampling of the vitrified material.

Performance Data Quality

Soil sampling and analysis for the SITE Demonstration was conducted following EPA SW-846 analytical methods. No exceptions to the methods were noted in the available references. The SITE Technology Capsule, however, identified a possibility that other, non-EPA approved, methods may provide more accurate determinations for metals in vitrified materials. The vendor reported that all glass and underlying containment soil samples were analyzed by IEA Laboratories under "Level II QA/QC procedures;" no deviations from acceptable procedures were identified by the vendor.

TREATMENT SYSTEM COST

Procurement Process

EPA contracted with Geosafe Corporation to construct and operate the ISV system at the site. Geosafe used several subcontractors to implement specific aspects of the operation.

Information about the competitive nature of the procurement process is not available at this time. [10]

Treatment System Cost

Although final cost information is not yet available, preliminary treatment system cost information is available from EPA, as presented in Tables 10-13. An action memorandum identified cost ceilings for this application totalling $3,466,967, including $1,763,000 for the cleanup contractor, as shown in Table 10. [1] In negotiating the contract with Geosafe, EPA established objectives for nine cost elements, as shown in Tables 11-13. The delivery order for Geosafe specified a ceiling value of $1,690,305. The reason for the discrepancy between the $1,763,000 and $1,690,305 values is not available at this time. [24]

In order to standardize reporting of costs among projects, costs are shown in Tables 11-13 according to the format for an interagency Work Breakdown Structure (WBS). The WBS specifies 9 before-treatment cost elements, 5 after-treatment cost elements, and 12 cost elements that provide a detailed breakdown of costs directly associated with treatment. Tables 11, 12, and 13 present the cost elements exactly as they appear in the WBS, along with the specific activities, and unit cost and number of units of the activity (where appropriate), as provided in the Contract Negotiation Cost Objectives. [31]

Table 10. Cost Ceilings Shown in Action Memorandum [1]

Cleanup Contractor	$1,763,000
Contingency (15%)	$264,450
Subtotal	$2,027,450
TAT	$716,000
Extramural subtotal	$2,743,450
Extramural Contingency	$411,517
Total for Extramural Costs	$3,154,967
U.S. EPA Direct Costs	$120,000
EPA Indirect Costs	$192,000
TOTAL for Intramural Costs	$312,000
TOTAL for Removal Project	3,466,967

TREATMENT SYSTEM COST (CONT.)

Treatment System Cost (cont.)

Table 11. Before-Treatment Cost Elements [Adapted from 31]

Cost Element	Cost Objective
Mobilization and Preparatory Work	
- Mobilization	$150,000
- Site Administration	$220,000
- Site Preparation	$4,000
Monitoring, Sampling, Testing, and Analysis	
- Soil	$80,000
- Glass	$10,000
- Air	$130,000
- Water	$25,000
Site Work	
- Uncontaminated Soil	$80,000
- Contaminated Soil	$100,000

Table 12. Treatment Cost Elements [31]

Cost Element	Cost Objective
Operation (short-term - up to 3 years)	
- Vitrification	$800,000

Table 13. After-Treatment Cost Elements [Adapted from 31]

Cost Element	Cost Objective
Site Restoration	
- Backfill and Grade	$80,000
- Seeding	$4,500
- Drainage Structures	$2,500
Demobilization	$77,000

Cost Data Quality

Limited data are available at this time to assess the cost for this treatment application. The cost data shown in this report were provided by EPA as contract negotiation cost objectives.

Vendor Input

The vendor stated that the costs for the application at Parsons were unusually high, and expects that the costs for future applications will be lower. Key factors affecting costs for ISV include: [41]

- Cost of the local price of electricity;
- Depth of processing;
- Soil moisture content; and
- Treatment volume.

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- The cleanup contractor's cost ceiling for the ISV treatment application at Parsons was $1,763,000, including $800,000 for vitrification operations, which corresponds to $270 in costs for vitrification per cubic yard of soil treated.
- The before-treatment costs for this application of $800,000 were high because of the need to excavate and stage the wastes prior to treatment.

Performance Observations and Lessons Learned

- Confirmation samples could not be obtained for this application until after the melt had cooled. As such, confirmation of the cleanup was made approximately one year after completion of the technology application.
- Confirmation coring sampling performed after the ISV melt had cooled for approximately one year indicated that the vitrified material in three drill holes had mercury and pesticide concentrations below detection limits, as measured using a TCLP analysis, and that volatiles and semivolatiles in the containment soil beneath the three drill holes were below detection limits. These data indicate that the vitrified material met the cleanup goals for this application, and that volatiles and semivolatiles were not measured in the soil beneath the vitrified material.
- The surface soil samples and stack gas emissions measured during the SITE Demonstration (melt 6 of 8), and the typical stack gas emission results provided by the vendor, met the soil cleanup standards and emissions standards for this application.
- Typical stack gas emissions for chlordane and 4,4'-DDT were several orders of magnitude lower than the ARARs.
- Based on the results of the SITE demonstration:
  1. The total waste analysis concentrations in surface soil samples were reduced from levels as high as 23,100 μg/kg to levels less than 11 μg/kg for chlordane, 4,4'-DDT, and dieldrin.
  2. Concentrations of metals in a TCLP extract of surface soil samples were reduced from as high as 21,000 μg/L to levels less than 5,000 μg/L.

Other Observations and Lessons Learned

- Vitrification was selected as the remedy based on its potential to reduce volume by 20 to 30% and decrease toxicity to near zero. Based on the results of the SITE demonstration, a volume of reduction of approximately 30% was achieved for the test soil. Based on the results of confirmation sampling, the level of contaminants was reduced to below detectable levels.
- Problems with cell design were observed during treatment of the first few cells, including decomposition of particle board forms, volatiles, phenolics, and epoxies in the diversion system water, and irregular melt shapes.
- Parsons was the first application of vitrification technology at a Superfund site.

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Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Radian International under EPA Contract No. 68-W3-0001 and U.S. Army Corps of Engineers Contract No. DACA45-96-D-0016.

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

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 other 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.

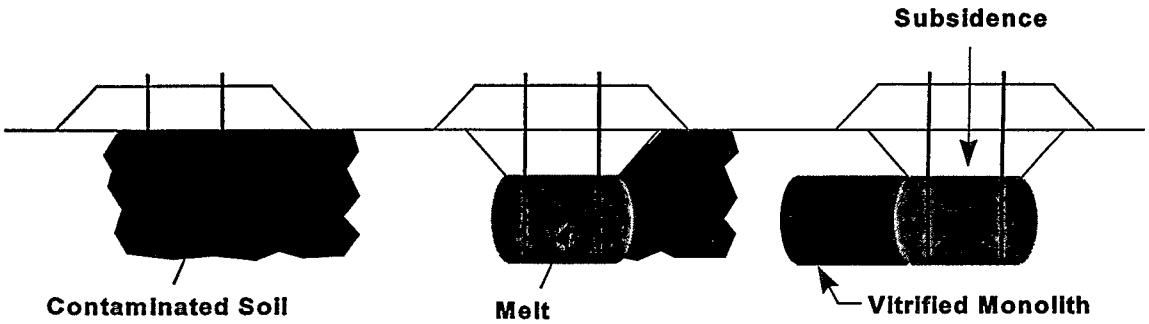
Site requirements for ISV, as identified by the vendor, are a function of: (1) the size and layout for equipment used in the process; (2) the staging area requirements for treatment cell construction; and (3) the area needed for maneuvering and operating equipment, excavating soils, and preparing treatment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

SECTION I

SUMMARY

Technology Description

In situ vitrification (ISV) is a thermal process for remediation of contaminated soil, sediment, sludge, mill tailings, and other earthen materials containing hazardous and radioactive contaminants (mixed waste). ISV is one of the few technologies that can simultaneously treat wastes with high concentrations of both organic and inorganic contaminants (e.g., heavy metals, radionuclides) (Figure 1).



- **1600-2000°C (soils)**
- **3-5 ton/hr melt rate**
- **5-20 ft depth (single melt)**
- **500-1000 ton melts (typ)**
- **Limitations exist for organic content, water recharge rate, large voids, size and quantity of debris, and sealed containers**

Figure 1. Overview of the in situ vitrification process.

Contaminants are either destroyed, immobilized, and/or removed during ISV treatment. Gases generated by the ISV process are collected in a hood and treated by an off-gas treatment system before discharge. Most metals, radionuclides, and other inert materials are retained in the melt (Figure 2). When cooled, the melt becomes a monolithic structure resembling obsidian or other forms of natural volcanic rock.

ISV also has a high tolerance for debris and other waste materials that might be in the treatment area (e.g., wood, scrap metal, concrete, boulders, asphalt, plastics, tires, or vegetation). Underground structures such as storage tanks, piping, and cribs may be able to be vitrified in place.

Technology Status

The ISV process was conceived in 1980 by Battelle Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy (DOE). Since then, more than 200 development tests, demonstrations, and commercial operations of the technology have been conducted, ranging from bench-scale to full-scale commercial melts at various sites. The Idaho National Engineering and Environmental Laboratory participated in the ISV technology development activities, conducting bench- and pilot-scale testing.

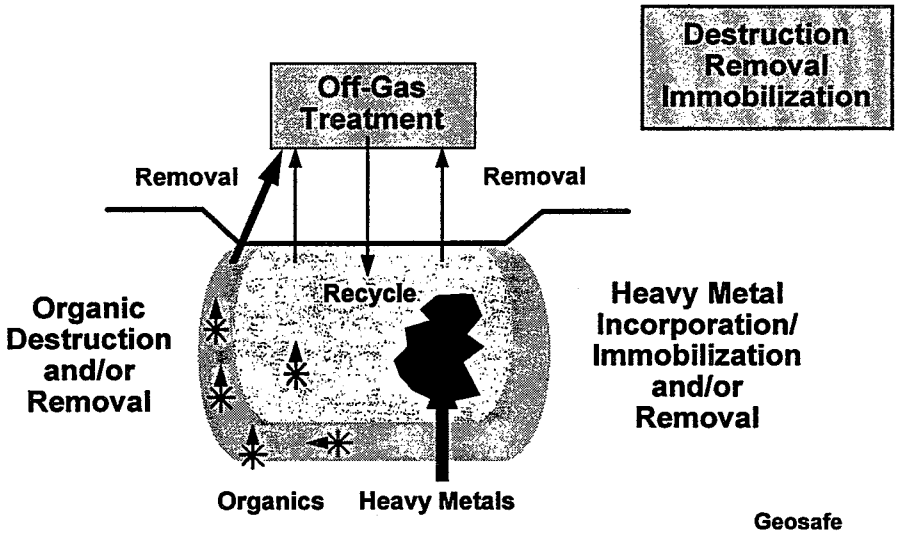


Figure 2. Contaminant disposition.

Geosafe Corporation licensed the ISV technology from PNL to apply ISV commercially to known contaminated soils for environmental restoration and waste treatment needs. Geosafe has successfully performed three large-scale commercial remediations in the United States and numerous test projects.

- The first commercial project was performed at the Parsons Chemical Superfund site and was included in the U.S. Environmental Protection Agency (EPA) SITE program. This first remediation involved soils contaminated by pesticides and metals.
- The second commercial remediation was a Toxic Substances Control Act (TSCA) demonstration for soils contaminated with polychlorinated biphenyls (PCBs). This second remediation resulted in the issuance of a national TSCA Operating Permit for PCBs.
- The third remediation project was performed on a Superfund site heavily contaminated with volatile, semivolatile, and nonvolatile organics, including dioxin, herbicides, and pesticides.

In the three U.S. remediations, the process was evaluated in detail for off-gas emissions, surrounding adjacent soils, and product quality.

Full-scale ISV operations have been successfully conducted on sites containing significant quantities of combustibles such as wooden timbers, automobile tires, personal protective equipment, and plastic sheeting. The process has also been tested in Japan and Australia, where Geosafe subsidiaries have been licensed to apply the ISV process.

Key Results

- ISV simultaneously processes mixtures of waste types, including both organic and inorganic contaminants.
- Treatment is effective in terms of reduction of toxicity/mobility, speed, and permanence.
- Substantial (20% to 50% for soils) volume reductions are achieved.
- ISV produces a superior residual product in terms of physical, chemical, and weathering properties and volume reduction.

- ISV is cost-effective on difficult sites.
- ISV is effective in achieving on-site and in situ safety and cost benefits.
- ISV can treat mixed waste (hazardous and radioactive) directly by thermally destroying organic and some inorganic components and immobilizing inorganic and most radioactive components in a vitrified product with outstanding life expectancy.
- ISV technology is applicable to earthen materials such as soil, sludge, sediments, mill tailings, and incinerator ash and has a high tolerance for debris.
- Multiple melts are required to treat large areas. When melt settings overlap previous melts, the melts fuse together into a large vitrified block.

The technology is still under refinement for applications involving liquid-bearing sealed containers or subsurface conditions where large amounts of water may move through the subsurface to the treatment zone rapidly. Such conditions may result in an excessive water vapor generation rate, which in turn can upset the melt and result in melt displacement and overheating of the off-gas collection hood.

Such a melt expulsion event occurred during a recent large-scale treatability test at the Oak Ridge National Laboratory (ORNL) WAG 7 site; however, project personnel performing tasks at the site at the time were not injured or contaminated during the incident, and air samples that were taken from the hood perimeter did not show any airborne contamination.

This event has indicated the need for additional precautions related to personnel and equipment safety when dealing with sites containing large amounts of free water. The means to avoid such occurrences include dewatering of sites containing large amounts of free water and other methods of preventing rapid recharge to the treatment zone. The event also confirmed that the high retention of ^{137}Cs and other radionuclides within the vitrified material minimizes the risk of any radiological release during such events.

All issues related to the ORNL WAG 7 event are being resolved, and remediation using ISV is expected to resume at WAG 7 in September 1996.

Contacts

Technical

Craig Timmerman, Manager, Engineering and Technology, Geosafe Corporation, (509) 375-0710

Management

James E. Hansen, Vice President, Business Development and Communications, Geosafe Corporation, (509) 375-0710

James Wright, DOE Subsurface Contaminant Focus Area Manager, (803) 725-5608

Site

Brian Spalding, Oak Ridge National Laboratory, (423) 574-7265

SECTION 2

TECHNOLOGY DESCRIPTION

Process Schematic

ISV is a patented process that destroys most organic and some inorganic compounds by thermally induced decomposition (pyrolysis) in an oxygen-depleted environment in and around the melt zone. Pyrolyzed compounds are typically broken down to their elemental components. Volatile components travel to the surface of the melt where they are collected in a hood. Residence time within the hood allows the components to be oxidized. The remaining volatile components and carryover particulates are captured and treated by an off-gas treatment system (Figure 3).

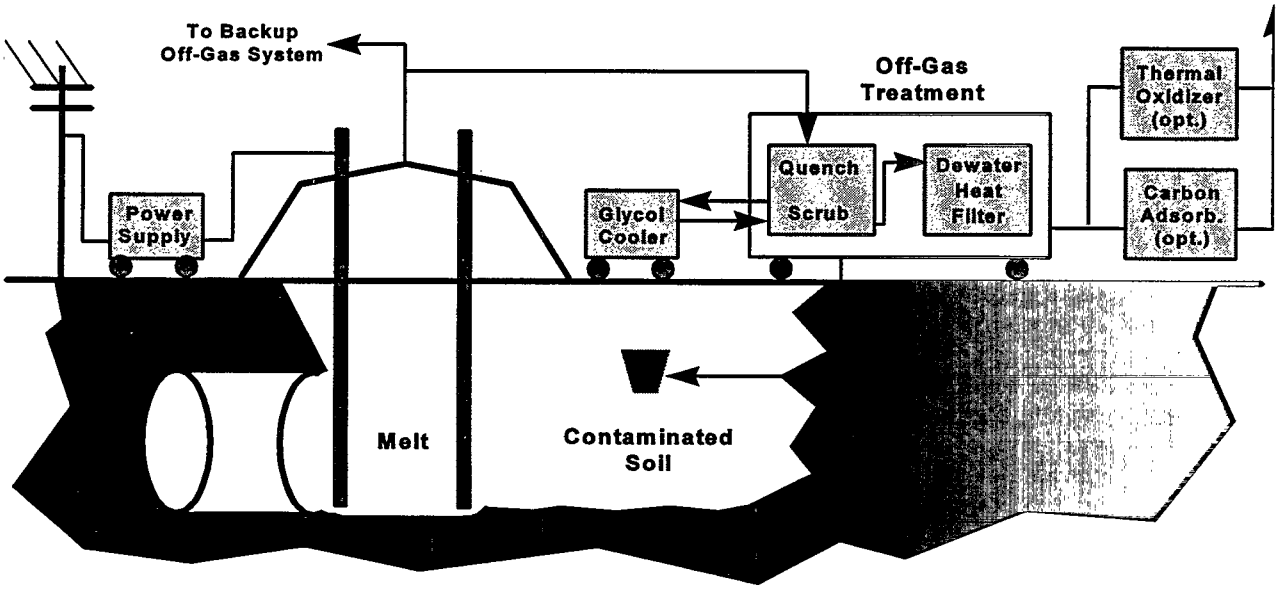


Figure 3. Overall in situ vitrification process system.

The volatile contaminants present on the site affect the off-gas treatment system more dramatically than they affect the rest of the ISV system. For that reason, the off-gas treatment system is modular in configuration, thus allowing treatment of the off-gas to be site specific. Contaminants that remain in the molten soil (heavy metals and radionuclides) are incorporated into the vitrified product. The vitrified product is a chemically stable, leach-resistant, glass and crystalline material similar to obsidian or basalt rock. As a result of densification, volume reductions of 20% to 50% are typical.

To initiate the melt, electric potential is applied to graphite electrodes.

- Current initially flows through a starter path of highly conductive graphite and glass frit.
- As the starter path heats up, it melts the surrounding soil.
- The process produces temperatures of about 1600° to 2000°C. Once the soil is molten, it becomes electrically conductive.

- Continued application of electricity results in Joule heating within the molten soil between the electrodes.
- After the melt is established, the melt zone grows steadily downward and outward through the contaminated soil. Gases generated are collected and treated before discharge.

The rate of melting and other operating parameters are dependent on soil type, moisture content, and contaminant loading. A 60-ft-diam hood is placed over the vitrification zone to contain and collect gases emanating from the melt and adjacent soil. The off-gas treatment system keeps the hood under slightly negative pressure.

During ISV processing, water vapor and other vapors form in and move through the dry zone adjacent to the melt toward the ground surface under the hood. The normal pathway for vapor movement is within the dry zone; however, if relatively high vapor generation rates are experienced, it is possible for vapors to intrude and move through the melt to the surface. Under extreme conditions of vapor generation, movement of vapors through the melt can cause undesirable melt disturbances, including partial melt displacement. Such extreme conditions can occur during the treatment of liquid-bearing sealed steel containers or when melting below the water table in geologic conditions that may allow rapid intrusion of water to the treatment zone. Such conditions can be avoided by pretreating liquid-bearing sealed steel containers so as to violate their seals. Similarly, some means (e.g., pumping, dewatering, or intercept trenches) may be required to limit or prevent recharge of water to the treatment zone when treating below the water table.

Ancillary Equipment/Systems

The electric power requirements on site for the ISV process are 4 MW of 3-phase, 60-cycle, ac power at 12.7 or 13.5 kV, from either a utility grid or a diesel generator. The power is converted to 2-phase and transformed to a variable level in the range of 400 to 4000 V, depending on melt size and conductivity. The maximum power delivered to the electrodes is 3.5 MW, which results in a maximum melting rate of about 5 ton/hr. The process requires 700 to 900 kWh/ton of soil treated, including the amount of water in the soil.

The off-gas treatment train is normally configured as follows: quencher, scrubber, demister, reheater, high-efficiency particulate air filters, and activated carbon adsorption and/or thermal oxidizer. Scrubbing system water may require treatment before discharge. Secondary effluents, contaminated equipment, and contaminated materials produced in the ISV process could possibly be collected and recycled to subsequent melts, thus minimizing secondary wastes.

SECTION 3

PERFORMANCE

Demonstration Overview

ISV technology has been demonstrated and transferred to the Geosafe Corporation. Geosafe has had three commercial remediations and numerous test melts. The first remediation project involved an EPA SITE program addressing pesticides and metals. The second project was a TSCA demonstration focusing on PCBs at a private Superfund site. The third demonstration addressed dioxins/furans, pesticides, herbicides, and considerable debris. The ISV technology performed as expected in these three applications. Typical performance parameters for ISV applications are summarized as follows:

- organic destruction and removal efficiency (DRE): 99.99% to >99.999999%;
- metals retention: 98% to > 99.9999% (Pu, U, Ra, Sr, and Cs);
- volume reduction: 20% to 50% (soils);
- permanence: geologic life expectancy;
- leachability: far surpasses Toxicity Characteristic Leaching Procedure (TCLP) and product consistency test (PCT); and
- maximum overall treatment effectiveness (reduction of toxicity, mobility, and volume).

Performance

The Parsons Chemical Superfund Site remediation project treated 4800 tons of clay soils contaminated with a variety of pesticides (DDT, dieldrin, and chlordane) and heavy metals (mercury, lead, and arsenic). The remediation site was independently monitored by EPA's SITE program and evaluated in an EPA technical report (EPA 1994). As indicated in Table 1, the level of contamination was reduced to below detection limits in most cases and below the state regulatory limits for all of the contaminants of concern.

Table 1. Pre- and post-in situ vitrification (ISV) soil contaminant concentrations (ppb)

Contaminant	Pre-ISV	Post-ISV	Regulatory limit
Mercury	24,160	33	12,000
Chlordane	2,010	<80	1,000
Dieldrin	11,630	<16	80
4,4-DDT	72,100	<16	80

Note: Data are from the Parsons site.

A TSCA demonstration project was performed at a private Superfund site in Washington state. The TSCA demonstration fulfilled the requirements to receive a national TSCA Operating Permit for the application of ISV to PCB-contaminated soils and debris. Five melts were performed to treat 3100 tons of contaminated soil and materials. The melts were staged to contain one or more of the following materials: concrete, asphalt, ruptured drums, and spiked soil up to 17,860 ppm PCBs. Soil adjacent to the treatment zone was analyzed before and after treatment. The results indicated a decrease in PCB concentration in the adjacent soil 60 to 90 cm from the melt boundary and no impact in the more distant

soils. Soil, vitrified product, and off-gas emission testing indicated that a typical DRE of more than 99.9999% was achieved for PCBs.

The Wasatch Chemical Site project involved remediating a concrete evaporation pond containing 5600 tons of contaminated sludge, soil, and debris. Debris consisted of wooden timbers, clay pipe, sample containers, scrap metal, smashed 55-gal drums, plastic sheeting, protective clothing, miscellaneous contaminated site soils, and a sludge heel from an evaporation process. Other contaminants included dioxins/furans, pentachlorophenol, pesticides, volatile organic compounds, and semivolatile organic compounds. Thirty-seven contiguous melts were performed to treat the complete volume of contaminated soil and debris. Off-gas analytical results confirmed the complete absence (nondetection) of dioxins/furans in the off-gasses. Sampling of soil surrounding the berm before and after ISV treatment indicated that no contamination migrated outside the melt. In addition, dip samples of the glass taken during the processing of three melts confirmed that no detectable organic contamination remained in the treated soil. The results of the pre-ISV melt, dip sampling of the vitrified product, and pre- and post-ISV surrounding soil sampling are presented in Table 2.

Table 2. Wasatch Chemical soil and glass sampling results (ppb)

Contaminant	Pre-ISV levels	Molten product dip samples	Surrounding berm pre-ISV	Surrounding berm post-ISV
Dioxin/Furan	12,400	ND	0.005	0.004
Pentachlorophenol	272,918	ND	NA	1.2
Tetrachloroethene	<100	ND	700	ND
Trichloroethene	36,875	ND	850	ND
2,4-D	34,793	ND	2.8	ND
2,4,5-T	1,137	ND	7.36	ND
4,4'-DDD	27	ND	ND	ND
4,4'-DDE	3,600	ND	ND	2.4
4,4'-DDT	5,305	ND	ND	ND
Total chlordane	2,368	ND	0.5	83.4
Heptachlor	137.5	ND	ND	ND
Hexachlorobenzene	17,000	ND	ND	ND

Abbreviations: ISV = in situ vitrification; NA = not analyzed; ND = not detectable.

Typical residual product properties are summarized as follows:

- composition: analogous to natural volcanic rock;
- strength: ten times unreinforced concrete;
- volume reduction: 20% to 50%;
- toxicity reduction: organics are removed/destroyed, and inorganic-bearing residual had acceptable biotoxicity (EPA);
- mobility reduction: surpasses TCLP, and PCT;
- wet/dry cycling: unaffected;
- freeze/thaw cycling: unaffected; and
- life expectancy: geologic time period.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

Technology Applicability

ISV is a stand-alone technology that can treat a wide variety of media, including contaminated soils, sediments, sludges, rocks, sand, silt, and clay that may contain radionuclides, transuranics, fission products, organic chemicals, metals, and other inorganic chemicals. Site characteristics should be favorable for ISV or be able to be modified to make the site suitable.

ISV is a mobile system mounted on three trailers. The hood and remaining equipment are transported on two additional trailers.

The basic ISV technology can be applied in a number of alternative configurations:

- in situ;
- staged in situ, where contaminated media and waste have been placed (staged) for treatment, either above, below, or above and below grade; and
- stationary/batch or continuous modes.

Figures 4 and 5 illustrate the possible configuration alternatives.

Because of this flexibility, ISV may be applied to a broad range of contaminated media situations:

- contaminated soils;
- buried wastes;
- contaminated below-grade structures (e.g., tanks, pipes, cribs, and vaults);
- construction and decommissioning debris (e.g., concrete, asphalt, and structural and scrap metal); and
- mixed waste (e.g., low-level radioactive and transuranic).

In some of these cases, pretreatment (e.g., dynamic disruption) of the contaminated media may be necessary before ISV processing.

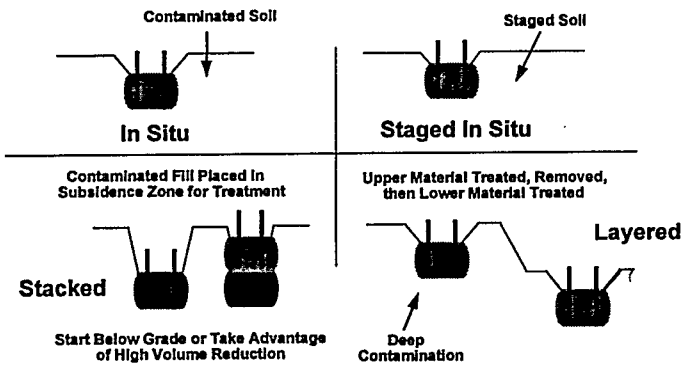


Figure 4. In situ vitrification treatment alternatives-1.

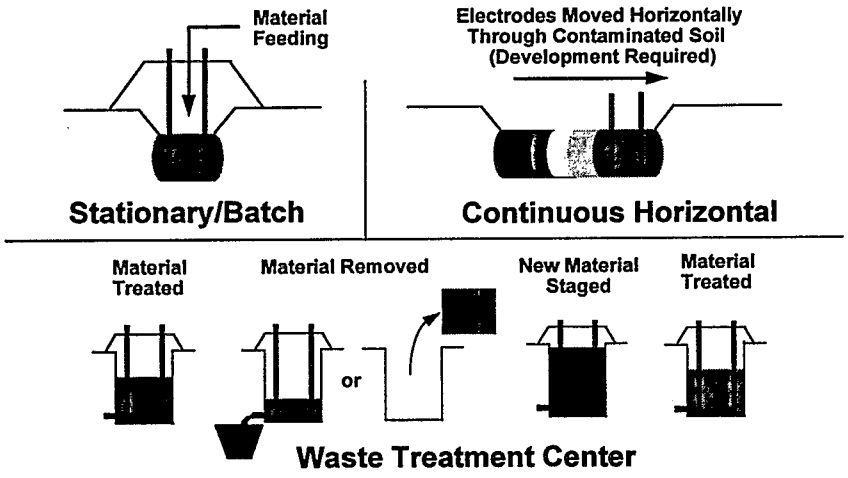


Figure 5. In situ vitrification treatment alternatives-2.

Alternative Technologies

- In situ grouting with monitoring.
- Retrieving, grouting, and reburial on site with monitoring.
- Exhumation and reburial of pit contents in an engineered landfill with monitoring.
- In situ barriers for the side walls and floor with monitoring.
- Retrieval and thermal desorption with off-gas treatment.
- Retrieval and incineration with off-gas treatment. (This alternative is most similar to ISV; consequently, this method was selected for the cost comparison.)

SECTION 5

COST

Introduction

The cost estimates used in this report are based on data in the EPA SITE technology report on the Parsons Chemical Superfund site (EPA 1994).

The primary cost elements include utilities (largely the local price of electricity), consumables, labor, mobilization and startup, facilities modifications, maintenance, equipment used and remaining on site, and amortization of transportable equipment. Typical elements of project cost follow. (Note: items that have a dollar amount assigned to them are items that are typically provided by Geosafe. The other items are activities that are usually provided by support contractors under contract to the client or under subcontract to Geosafe.)

- Treatability/pilot testing ($50K to 150K).
- Remedial design.
- Site preparation (power; staging; preconditioning, if any).
- Mobilization ($150K to 200K).
- Vitrification operations ($375 to 425/ton).
- Demobilization ($150K to 200K).
- Site restoration.
- Long-term monitoring (operations and maintenance).

Power requirements are as follows:

- 4 MW maximum at 12.7 or 13.5 kV;
- 3-phase, 60-cycle ac;
- Utility grid or diesel generation; and
- 700 to 900 kWh/ton treated.

ISV consumes 50% to 70% less thermal energy than incineration and 20% less energy than simple trucking of soil to a landfill.

The cost estimates for treatment using Geosafe technology were based on the following assumptions.

- The contaminated soil is staged into treatment cells by an independent contractor before Geosafe's arrival on-site. Cell preparation and construction are site specific and may be different for each site; however, it is assumed that each site is prepared in a similar manner to the Parsons site.
- The depth of treatment is assumed to exceed the depth of contamination by at least 1 ft to ensure that the melt incorporates the floor of the cell and beyond.
- Treatment takes place 24 hrs/day, 7 days/week, 52 weeks/year. An on-line efficiency factor of 80% has been incorporated to account for downtime for scheduled and unscheduled maintenance and other unforeseen events.
- Operations for a typical shift require one shift engineer and one operator. In addition, one site manager and one project control specialist are present on-site during the day shift. Three shifts of workers are assumed to work 8 hrs/day, 7 days/week for 3 weeks. At the end of 3 weeks, a shift of

workers are assumed to work 8 hrs/day, 7 days/week for 3 weeks. At the end of 3 weeks, a shift of workers is rotated out and a new set of workers replaces them.

- The costs presented (in dollars per cubic yard) are calculated based on the number of cubic yards of contaminated soil treated. Because clean fill and surrounding uncontaminated soil are treated as part of the melt, the total number of cubic yards of soil treated is higher than the number of cubic yards of contaminated soil treated. Costs per cubic yard based on total soil treated would, therefore, be lower than the costs presented in this estimate.

If Geosafe scales its process differently than assumed in this analysis, then the cost of remediation per cubic yard of contaminated soil will change.

These cost estimates are representative of charges typically assessed to the client by the vendor and do not include profit. The developer claims these costs were unusually high and expects the treatment costs for future sites to be less than the treatment costs for the Parsons site.

Table 3 presents a general order of magnitude estimate for the cost of remediating a site. The estimate represents capital and operating costs based on treating about 3200 yd^3 or about 5700 tons of contaminated soil at the Parsons site.

Table 3. In situ vitrification cost estimates (based on Parsons site experience)

Volume (yd^3)	Cost ($/$yd^3$)	Cost ($/ton)
970	1500	833
3200	780	433
4400	670	372

Note: The Parsons site had unusually high soil density.

Geosafe notes that the cost estimates prepared by the SITE program are significantly higher than its own commercial experience. For reference purposes, Geosafe's prices typically fall in the range of $375 to $425/ton for vitrification operations. Mobilization and demobilization of the 100 ton/day system can cost in the range of $300K to 400K (combined total). Preconditioning of the site may cost additional. Geosafe finds that the bottom line cost per ton for most sites falls in the range of $400 to $600/ton, depending on size, location, and site preparation needs.

Cost Comparison

The cost comparisons used in this report are based on data reported by Showalter et al. (1992). The mobile rotary kiln incinerator was chosen for the baseline because of its flexibility and low capital cost combined with the minimal decontamination and decommissioning cost at the end of its useful life. The site developed for this comparison is similar to mixed waste trenches and pits that are found on DOE property. The site in this comparison is 30-m wide × 90-m long × 5-m deep. The soil is homogeneous and contaminated with low-level radioactive mixed waste. The soil moisture content is 5%.

The site is considered to be in a flat, readily accessible area and will require only minimum clearing and leveling before remediation. The perimeter fencing will be 10-ft high with four-strand razor wire topping.

Factors

- Capital equipment costs are similar for the two technologies. ISV costs slightly more because of the decision to generate power on site. (When electric power in sufficient quantities is not available from

an electric utility, a generator must be purchased for on-site.) Purchasing power from a local utility would eliminate the need to purchase a generator.

- Mobilization of the ISV system is much more labor intensive than it is for incineration.
- The ISV system includes extensive sampling of the vitrified area to verify that the final waste form is acceptable. Both estimates include extensive stack sampling and analysis. Incineration incurs more than twice the cost of ISV in this category because of much larger air flow through the incinerator.
- Although incineration operates for a shorter time, it has a higher labor cost during operation. One reason for this is the increased worker protection requirements for incineration over ISV.
- ISV is more expensive in the consumables category.
- The cost of secondary disposal is the most expensive component of the cost of incineration. ISV creates a vitrified mass that may be left in place, while incineration requires that the residual be moved to monitored storage.
- Where secondary disposal is eliminated, the total cost of incineration will be similar to the total cost of ISV. If only a hazardous organic component had to be destroyed, there would be little or no waste to be disposed of under incineration. Allowing a minimal cost for secondary waste in each case and reducing the cost risk factor accordingly results in incineration being roughly $500/m^3$, slightly less than ISV, which costs about $600/m^3$.

Costs Considered

Examination of the specific cost categories listed in Table 4 highlights the differences in cost. Several costs have been left out of the analysis, but only after deciding that they would be similar between the two processes. Costs included in this analysis are capital (equipment); site preparation; mobilization and demobilization (mobilize/demobilize, crew relocation, site administration, ISV melt analysis, backfill and grade, and decommission and dispose); operations (stack sampling, labor, consumables, subcontractors, and oversight engineer); secondary waste disposal; miscellaneous (includes environmental impairment insurance); labor and material; performance bonds; and escalation.

Table 4. Cost comparison of in situ vitrification (ISV) and incineration for a 30-m-wide × 90-m-long × 5-m-deep mixed waste site

Cost category	ISV: total scenario cost ($)	ISV: cost per cubic meter ($)	Incineration: total scenario cost ($)	Incineration: cost per cubic meter ($)
Capital	1,038,654	76.94	775,557	57.45
Site preparation, mobilization, and demobilization	1,681,702	124.57	1,074,212	79.58
Operations	3,694,430	273.65	3,016,930	223.48
Secondary waste disposal	1,038,310	76.91	17,877,816	1,324.28
Miscellaneous	307,468	22.78	270,000	20.00
Labor, material, and performance bonds	100,954	7.48	345,218	25.57
Escalation	156,147	11.57	366,367	24.92
Total	8,017,665	593.90	23,726,100	1,755.28

Cost Summary

Based on this scenario, ISV is significantly less expensive than incineration. ISV costs about $600/m^3$ versus roughly $1755/m^3$ for incineration. Table 4 shows the comparison of the major cost categories.

SECTION 6

REGULATORY/POLICY ISSUES

Regulatory Considerations

Table 5 presents a regulatory analysis of ISV technology using Comprehensive Environmental Response, Compensation, and Liability Act (1980) criteria.

Safety, Risks, Benefits, and Community Reaction

The EPA Technology Innovation Office is encouraging the inclusion of ISV technology in remedial investigations, feasibility studies, records of decision, and remedial design. State regulatory agencies have accepted the ISV process where demonstrations and remediations have been proposed.

Site preparation or pretreatment steps that include water removal by pumping or diversion and barrier systems to avoid recharge to the zone to be vitrified may be necessary to reduce the risk of a melt expulsion event (MEE) at some sites. In an MEE, a buildup of vapor pressure occurs and results in a sudden intrusion of vapor into and through the ISV melt. Detailed site characterization and quantitative modeling may be required to evaluate the nature and extent of necessary pretreatment.

Benefits Summary

Safety, regulatory, and other benefits are summarized in Figure 6.

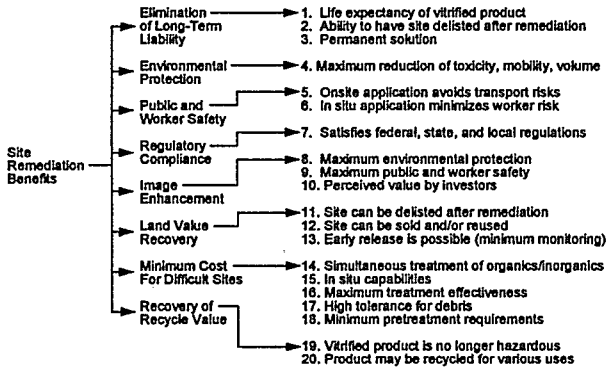


Figure 6. Remediation benefits related to technology features.

Community Reaction

Some stakeholders, primarily those living near sites, have expressed concerns about public and worker safety. The effectiveness of the ISV process has also been questioned. Close communication and coordination with local stakeholders early in the planning stage should help identify and address their concerns.

Table 5. Regulatory analysis of the Geosafe in situ vitrification (ISV) technology using Comprehensive Environmental Response, Compensation, and Liability Act criteria

Overall protection of human health and the environment	Compliance with ARARs	Long-term effectiveness	Short-term effectiveness	Reduction of toxicity, mobility, or volume through treatment	Implementability	Cost
Provides both short- and long-term protection by destroying organic contaminants and immobilizing inorganic material.	Requires compliance with RCRA treatment, storage, and land disposal regulations (for a hazardous waste). Successfully treated solid waste may be delisted or handled as nonhazardous waste.	Effectively destroys organic contamination and immobilizes inorganic material.	Effectively destroys organic contamination and immobilizes inorganic material.	Significantly reduces toxicity and mobility of soil contaminants through treatment.	A suitable source of electric power is required to use this technology.	The estimated cost for treatment when the soil is staged into nine 15-ft-deep cells is about \$780/yd^3 (\$430/ton). This cost is based on data gathered from the Parsons site. Costs are highly site-specific and will vary with on-site conditions.
Remediation can be performed in situ, thereby reducing the need for excavation.	Operation of on-site treatment unit may require compliance with location-specific ARARs.	Reduces the likelihood of contaminants leaching from treated soil. ISV glass is thought to have a stability similar to volcanic obsidian. The vitrified product is conservatively estimated to remain physically and chemically stable for about 1000 years.	Vitrification of a single 15-ft-deep treatment setting may be accomplished in about 10 days. Treatment times will vary with actual treatment depth and site-specific conditions.	Volume reductions of 20% to 50% are typical after treatment.	Equipment is transportable and can be brought to a site using conventional shipping methods. Weight restrictions on tractors/trailers may vary from state to state.	Treatment is most economical when treating large sites to maximum depths.
Technology can simultaneously treat a mixture of waste types (e.g., organic and inorganic wastes).	Emission controls may be needed to ensure compliance with air quality standards depending on local ARARs and test soil components.	May allow reuse of property after remediation.	Presents potential short-term exposure risks to workers operating process equipment. Temperature and electric hazards exist.	Some inorganic contaminants, especially volatile metals, may escape the vitrification process and require subsequent treatment by the off-gas treatment system.	Necessary support equipment includes earth-moving equipment for staging treatment areas with clean soil. A crane is required for off-gas hood placement and movement.	Electric power is a major element of costs associated with ISV processing. Other important factors (in order of significance) include labor costs, startup and fixed costs, equipment costs, and facility modifications and maintenance costs.

Table 5. (Continued)

Overall protection of human health and the environment	Compliance with ARARs	Long-term effectiveness	Short-term effectiveness	Reduction of toxicity, mobility, or volume through treatment	Implementability	Cost
	Scrubber water will likely require secondary treatment before discharge to POT or surface bodies. Disposal requires compliance with Clean Water Act regulations.		Some short-term risks associated with air emissions are dependent upon test material composition and off-gas treatment system design.	Some treatment residues (e.g., filters and personal protective equipment) may themselves be treated during subsequent vitrification settings. Residues from the final setting, including expended or contaminated processing equipment, may require special disposal requirements.	The staging of treatment areas is recommended for areas where the contamination is limited to shallow (less than 8 ft) depths.	Moisture content of the media being treated directly influences the cost of treatment as electric energy must be used to vaporize water before soil melting occurs.
			Staging, if required, involves excavation and construction of treatment areas. A potential for fugitive emissions and exposure exists during excavation and construction.	Volume of scrubber water generated is highly dependent upon soil moisture content, ambient air humidity, and soil particulate levels in the off-gas.	The soil oxide composition must provide sufficient electrical conductivity in the molten state and adequate quantities of glass formers to produce a vitrified product. Oxides can be added to soil to correct for deficiencies. Ground water should be diverted away from treatment areas to improve economic viability.	Sites that require staging and extensive site preparation will have high overall costs.

Abbreviations used: ARAR = applicable or relevant and appropriate requirements; RCRA = Resource Conservation and Recovery Act of 1976, and POT = publicly owned treatment works.

Source: EPA 1994.

SECTION 7

LESSONS LEARNED

Implementation Considerations

- A suitable source of electric power is required for this technology.
- Equipment is transportable and can be brought to a site using conventional shipping methods.
- Necessary support equipment includes a crane for placing and removing the off-gas hood, and earth-moving equipment may be needed.
- The staging of treatment areas is recommended for areas where contamination is limited to less than 8 ft to attain economic processing rates.
- The overall oxide composition of the soil determines the properties such as fusion and melt temperature and viscosity. Other constituents needed for acceptable glass formation must be present in the soil or be added.

Site Requirements

Site requirements for the Geosafe ISV technology are a function of (1) the size and layout for equipment used in the process; (2) the staging area requirements for the construction of treatment cells (if needed); and (3) the room required to maneuver equipment for excavating contaminated soils, preparing treatment cells, and placing and relocating equipment.

Technology Limitations/Needs for Future Development

- The maximum acceptable treatment depth with current equipment is 20 ft below ground surface.
- Water in the soil is removed by evaporation in advance of the melt. The process may be used in supersaturated media (e.g., 70 wt % water); however, the removal of water consumes energy and increases cost. Therefore, it is desirable to maintain the treatment zone at low water levels.
- Water vapor generated below grade passes to the surface through the dry zone adjacent to the melt. If vapor generation rates are very high, some vapor may pass through the melt itself. Excessive amounts of vapor passing through the melt may cause melt disruption (bubbling) and possible melt displacement (splattering). Therefore, it is necessary during the remedial design phase of a project to consider process conditions that will result in acceptable water vapor generation and removal rates.
- Buried steel drums that still have structural and sealing integrity and contain liquids hold the potential for introducing vapors through the melt disruptively. Site characterization should be sufficient to assess whether such liquid-bearing drums exist within a site. If they do, then they can be pretreated by dynamic disruption and/or compaction technologies so that they can be safely processed by ISV without melt disturbance.
- The overall oxide composition of the media being treated determines the melt properties (e.g., fusion and melt temperature and viscosity). It is essential that the media contain sufficient monovalent alkali earth oxides to provide the amount of electrical conductivity required of the melt. The amount of glass-forming oxides (e.g., silica and alumina) present is a primary determinant of the vitrified product physical, chemical leaching, and weathering properties. Typical soils throughout the world possess adequate properties to allow ISV processing and produce a high-quality vitrified product. In rare cases, additives may be necessary to obtain the electrical conductivity or vitrified product properties desired.

- The heat-removal limitations of the current equipment dictate that the organic content of the treatment media be less than 10 wt % if operating at full power level. Higher organic loading can be accommodated by operating at correspondingly lower power levels. Waste containing up to 25 wt % organics has been treated using existing equipment. Some chemical reduction of ferrous metal oxides may occur during ISV, resulting in pooling of iron at the bottom of the melt. Geosafe has performed melts containing up to 37 wt % scrap metal with no difficulty. Similarly, the process is highly tolerant of debris and rubble, and Geosafe has successfully treated soil containing more than 50 wt % of such materials.
- Upon completion of melting, clean backfill soil is placed in the subsidence volume that exists above the melt (because of volume reduction). The melt surfaces cool sufficiently quickly that heavy equipment may be operated above backfilled melts in less than 1 day. Sufficient cooling of the vitrified monolith to enable revegetation can take several months.

Three technology limitation areas warrant further development to increase the potential value of the technology for DOE needs. These limitations fall into the areas of (1) maximum attainable depth, (2) applicability to higher organic concentrations, and (3) processibility of liquid-bearing sealed containers.

- Relative to increased depth potential, Geosafe is exploring ways either to melt more deeply from the surface downward or to initiate melting at deeper depths with completion melting either upward or downward from the initiation depth. These areas of exploration hold the potential to increase significantly the depth capability of the technology.
- Relative to higher organic concentrations, Geosafe notes that this limitation is equipment related and is not an inherent limitation of the technology. Higher organic concentrations may be treated by using off-gas treatment equipment with greater flow and heat-removal capacity. Such equipment would have to be designed and built for specific site needs.
- Relative to the liquid-bearing sealed container issue, Geosafe has explored a number of pretreatment alternatives that may be used to remove this limitation. In addition, DOE and Geosafe are pursuing an alternative avenue of investigation. That alternative is designing off-gas collection hood and treatment equipment that is capable of withstanding the intermittent vapor pressure and volume surges and elevated temperatures associated with treatment of sealed containers containing liquids. Note that not all containers of liquids are subject to this limitation; only containers that are tightly sealed, that contain liquids, and that are capable of withstanding very high temperatures (e.g., steel containers) are subject to this limitation.

Field Observations

Approximately 60 large-scale ISV melts have been conducted successfully in the United States and abroad. During these melts, only four MEEs were observed. No worker exposure nor injuries have been reported. Environmental contamination was insignificant, largely because of containment within the glass melt itself and capture by the off-gas filter media. However, DOE considers worker safety and protection of the environment to be paramount and has conducted an ISV Workshop to examine the root cause(s) of MEEs and to provide recommendations to reduce or eliminate the potential for an MEE occurrence.

The ISV Workshop attendees concluded that the two necessary conditions for an MEE are as follows:

- a source of vapor (either pore water, water structurally bound in materials, CO_2 bound in materials, soil organic matter, or other volatiles such as organic contaminants), and
- a confining structure or zone of low hydraulic conductivity that prevents routine dissipation of pressure.

Because both conditions are believed to be necessary for an MEE occurrence, the elimination or reduction of either or both conditions would reduced or eliminate the probability of an MEE.

The ISV Workshop attendees have adopted the following recommendations.

- DOE should continue to pursue applications of ISV for contaminated soil remediation.
- Site characterization and site-specific planning, including projections of ISV performance (modeling), should be a part of every application. The degree of planning and prediction will vary according to site and contaminant conditions, but may include the following factors:
  - mineralogic makeup of the soils,
  - chemical composition of the waste and waste forms present,
  - porosity and effective porosity,
  - moisture content/saturation,
  - relative permeability for gases and liquids,
  - permeability as a function of temperature and pressure,
  - subsurface geological structure, and
  - engineered structures or barriers.
- Engineering measures to modify a site in preparation for ISV (e.g., dewatering or mechanical disruption) should be considered where an analysis of characterization data indicates the possibility of an MEE.
- Monitoring tools for use during ISV need to be developed, adapted, and improved.
- Engineering measures to control the impacts of MEEs were not considered during the workshop but merit further evaluation.

APPENDIX A

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This report was prepared by:

HAZARDOUS WASTE REMEDIAL ACTIONS PROGRAM
Oak Ridge, Tennessee 37831-7606
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400
Contact: Thomas B. Shope, Ph.D.
(423) 435-3256

in conjunction with:

The Colorado Center for Environmental Management
999 18th Street
Suite 2750
Denver, Colorado 80202
Contact: Dawn Kaback
(303) 297-0180 ext. 111

EPA
United States
Environmental Protection Agency
(5102G)
Washington, DC 20460

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