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Remediation Case Studies: Bioremediation

Federal Remediation Technologies Roundtable

Prepared by the

Member Agencies of the Federal Remediation Technologies Roundtable

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March 1995

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FOREWORD

This report is a collection of nine case studies of bioremediation 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.

There are four case study reports, organized by technology, in this series. In the future, the set will grow through periodic supplements tracking additional progress with site remediation. In addition to this report on bioremediation projects, the following volumes are available:

Remediation Case Studies: Groundwater Treatment;
Remediation Case Studies: Soil Vapor Extraction; and
Remediation Case Studies: Thermal Desorption, Soil Washing, and In Situ Vitrification.

Ordering information for these and other Roundtable documents is on the following page.

Walter W. Kovalick, Jr., Ph.D.
Chairman
Federal Remediation Technologies Roundtable

Ordering Instructions

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Abstracts of Remediation Case Studies [106pp]	EPA-542-R-95-001	Free	_______
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Remediation Case Studies: Bioremediation	PB95-182911	$17.50
Remediation Case Studies: Groundwater Treatment	PB95-182929	$17.50
Remediation Case Studies: Soil Vapor Extraction	PB95-182937	$25.50
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Other Federal Remediation Technology Roundtable (FRTR) documents available from NTIS:

Title	Number	Price*
Accessing Federal Databases for Contaminated Site Clean-Up Technologies (3rd Edition)	PB94-144540	$17.50
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Synopses of Federal Demonstrations of Innovative Site Remediation Technologies (3rd Edition)	PB94-144565	$44.50
Remediation Technologies Screening Matrix and Reference Guide (2nd Edition)	PB95-104782	$45.00

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INTRODUCTION

The purpose of this report is to provide case studies of site cleanup projects utilizing bioremediation. This report is one of four volumes which are the first in a series of studies that will be prepared by Federal agencies to improve future remedy selection at contaminated sites. For projects that are ongoing, interim findings will be updated in future publications as additional data become available.

The case studies were developed by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Defense (DoD), and the U.S. Department of Energy (DOE). They present cost and performance information for full-scale remediation efforts and several large-scale demonstration projects and were prepared retrospectively, based on available information and interviews with project personnel. The case studies are meant to serve as primary reference sources, and contain information on the site; contaminants and media treated; technology and vendor; 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. Full-scale cleanup efforts are not conducted primarily for the purpose of technology evaluation, and data collection is often limited to establishing compliance with contractual requirements or regulatory levels.

This volume contains reports on nine projects that include bioventing and land treatment technologies, as well as a unique, large-scale slurry-phase project. In these projects, petroleum hydrocarbons are the most frequent contaminants of concern. Two land treatment projects in this volume represent completed cleanups at creosote sites.

Table 1 provides a project summary including information on technology used, contaminants and media treated, and project duration. The 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 consistently. However, the case studies themselves vary in terms of the level of detail and format of the available cost data. Where possible, project costs were categorized 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, if possible, per pound of contaminant removed. Note that comparisons using the information in this column are complicated by the fact that calculated costs may only be available on a per cubic yard or per ton basis, and cannot be converted back-and-forth due to limited availability of soil bulk density data.

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.

Abstracts and On-Line Access

The case studies have been summarized in abstracts which precede each study and provide key project information in a consistent format. The abstracts are based on recommended terminology and procedures from the Guide to Documenting Cost and Performance for Remediation Projects.

The case study abstracts are also available on-line through EPA's Cleanup Information Bulletin Board System (CLU-IN). To access CLU-IN by modem, call (301) 589-8366, or to contact the CLU-IN help desk, call (301) 589-8368. CLU-IN is available on the Internet; the telnet address is clu-in.epa.gov or 134.67.99.13.

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[1]Additional information on the contents of the Work Breakdown Structure and on whom to contact for WBS and related information is presented in the Guide to Documenting Cost and Performance for Remediation Projects - see ordering instructions on page iii.

Table 1. Summary of Remediation Case Studies: Bioremediation

Site Name, State (Technology)	Contaminants Treated					Media (Quantity)	Project Duration	Highlights
	BTEX and/or TPH	Chlorinated Aliphatics	Explosives	Polynuclear Aromatic Hydrocarbons	Source of Contamination (Principal Contaminants)			
Brown Wood Preserving Superfund Site, FL (Land Treatment)				●	Lagoon (creosote)	Soil (8,100 yd^3)	12/89 - 7/90	Sum of 6 carcinogenic PAHs reduced from 100-280 mg/kg to 23-92 mg/kg
Eielson Air Force Base, AK (Bioventing)	●				Spills and leaks (JP-4 fuel)	Soil (not available)	Operational since 7/91	Use of various soil warming techniques to demonstrate technology effectiveness in a subarctic environment
French Ltd. Superfund Site, TX (Slurry-Phase Bioremediation)		●		●	Disposal pit, spills and leaks (benzene, vinyl chloride, benzo(a)-pyrene)	Soil and sludge (300,000 tons)	1/92 - 11/93	Large-scale treatment of a lagoon in place; novel air injection system used to minimize air emissions
Hill Air Force Base, Site 280, UT (Bioventing)	●				Spills and releases (JP-4 fuel)	Soil (not available)	Operational since 12/90	Optimized air flow rates to maximize bioremediation while minimizing volatilization
Hill Air Force Base, Site 914, UT (Bioventing Preceded by SVE)	●				Spill (JP-4 fuel)	Soil (5,000 yd^3)	10/88 - 12/90	System converted from SVE to bioventing after one year of operation
Lowry Air Force Base, CO (Bioventing)	●				UST (heating oil)	Soil (not available)	Operational since 8/92	Bioventing used to treat residual petroleum contamination in an excavated area
Lowry Air Force Base, CO (Land Treatment)	●				UST (heating oil)	Soil (not available)	Operational since 7/92	Soil contaminated with high levels of TPH (>11,000 mg/kg) and relatively low levels of BTEX (<100 mg/kg)
Scott Lumber Company Superfund Site, MO (Land Treatment)				●	Lagoon and spills (creosote)	Soil (15,916 tons)	12/89 - 9/91	Sum of 16 PAHs reduced from 560-700 mg/kg to 130-155 mg/kg; over 70% reduction in PAH concentrations
Umatilla Army Depot Activity, OR (Composting)			●		Lagoon (TNT/RDX/HMX)	Soil (224 yd^3)	5/92 - 11/92	Field demonstration project using windrows

Key:

SVE - Soil Vapor Extraction
BTEX - Benzene, Toluene, Ethylbenzene, and Xylene
TPH - Total Petroleum Hydrocarbons

Table 2. Remediation Case Studies - Summary of Cost Data for Bioremediation Projects

Site Name, State (Technology)	Project Cost ($)*	Quantity Treated	Calculated Cost for Treatment**	Key Factors Potentially Affecting Project Costs
Brown Wood Preserving Superfund Site, FL (Land Treatment)	T - 565,406 B - 58,000 A - 9,800	8,100 cubic yards of soil	$70/cubic yard of soil treated	Treatment using 3 lifts; system constructed using a clay liner and underdrain system; cleanup completed 6 months ahead of schedule
Eielson Air Force Base, AK (Bioventing)	C - 758,077 (includes design and engr.) O - 177,160	Not available	Ongoing field demonstration	Includes costs for floating fuel collection and groundwater monitoring not associated with bioventing
French Ltd. Superfund Site, TX (Slurry-Phase Bioremediation)	T - 26,900,000 B - 16,500,000 A - 5,600,000	300,000 tons of soil and sludge	$90/ton of soil and sludge treated	Excavation not required for treatment; relatively large quantity treated resulted in economies of scale
Hill Air Force Base, Site 280, UT (Bioventing)	C - 115,000 O - 24,000	Not available	Ongoing full-scale cleanup	One injection well, relatively small project
Hill Air Force Base, Site 914, UT (Bioventing)	T - 599,000	5,000 cubic yards of soil	$120/cubic yard of soil treated	Four injection wells, relatively high concentrations of contaminants
Lowry Air Force Base, CO (Bioventing)	C - 28,650 (includes design and engr.) O - 32,875	Not available	Ongoing full-scale cleanup	Relatively shallow bioventing system
Lowry Air Force Base, CO (Land Treatment)	C - 104,257 (includes design and engr.) O - 18,460 (estimated operating costs)	Not available	$19/ton estimated cost; assumes 3.5 years to complete treatment	Treatment using one lift; non-RCRA liner
Scott Lumber Company Superfund Site, MO (Land Treatment)	T - 1,292,000 (1989-1991) 254,000 for laboratory analyses	15,961 tons of soil	$81/ton of soil treated	Treatment using 2 lifts; system constructed using a clay liner and underdrain system

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.

Table 2. Remediation Case Studies - Summary of Cost Data for Bioremediation Projects (Continued)

Site Name, State (Technology)	Project Cost ($)*	Quantity Treated	Calculated Cost for Treatment**	Key Factors Potentially Affecting Project Costs
Umatilla Army Depot Activity, OR (Composting)	T - 1,840,000 B - 2,000,000 (projected for full-scale operation)	Projected costs based on treatment of 20,000 tons of soil	$92/ton projected based on 5 years treatment, and compliance with RCRA Waste Pile Facility Standards	Costs estimated based on results of 40-day demonstration

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.

BIOREMEDIATION CASE STUDIES

Land Treatment at the Brown Wood Preserving Superfund Site Live Oak, Florida

Land Treatment at the Brown Wood Preserving Superfund Site, Live Oak, Florida

Site Name:
Brown Wood Preserving Superfund Site

Location:
Live Oak, Florida

Contaminants:
Polynuclear Aromatic Hydrocarbons (PAHs)
- Primary constituents in creosote
- Total PAH concentrations in stockpiled soil ranged from 100 to 208 mg/kg

Period of Operation:
January 1989 to July 1990

Cleanup Type:
Full-scale cleanup

Vendor:
John Ryan
Remediation Technologies, Inc. (ReTeC)
1011 Southwest Klickitat Way, Suite 207
Seattle, WA 98134
(206) 624-9349

SIC Code:
2491B (Wood Preserving using Creosote)

Technology:
Land Treatment
- Construction of the land treatment area (LTA) included installation of a clay liner, berm, run-on swales, and a subsurface drainage system
- Retention pond for run-off control; portable irrigation system
- Treatment performed using three lifts of soil; first lift inoculated with PAH - degrading microorganisms
- Lifts cultivated once every two weeks; soil moisture content maintained at 10%

Cleanup Authority:
CERCLA
- ROD Date: 4/8/88
- PRP Lead

Point of Contact:
Martha Berry
Remedial Project Manager
U.S. EPA Region 4
345 Courtland Street, N.E.
Atlanta, GA 30365
(404) 347-3016

Waste Source:
Manufacturing Process; Lagoon

Purpose/Significance of Application:
This was one of the early applications of land treatment of creosote-contaminated soil at a Superfund site.

Type/Quantity of Media Treated:
Soil
- 8,100 cubic yards of soil treated in three lifts
- Mixture of lagoon contents; lagoon had a clay bottom and sandy contents, which ranged from silty clay to fine sand

Regulatory Requirements/Cleanup Goals:
- ROD specified cleanup goals for PAHs in terms of Total Carcinogenic Indicator Chemicals (TCICs)
- TCICs defined as the sum of the concentrations of six constituents: benzo(a)anthracene; benzo(a)pyrene; benzo(b)fluoranthene; chrysene; dibenzo(a,h)anthracene; and indeno(1,2,3-cd)pyrene
- ROD required reduction of TCIC concentration to 100 mg/kg within two years of initial seeding

Results:
- The cleanup goal was achieved within 18 months
- TCIC concentrations at 18 months ranged from 23 to 92 mg/kg

Land Treatment at the Brown Wood Preserving Superfund Site, Live Oak, Florida (Continued)

Cost Factors:
- Total costs for treatment activities at this site were approximately $565,400 (including solids preparation and handling; mobilization/setup; and short-term (up to 3 years) and long-term (over 3 years) operation costs)
- Over half of total costs (about $312,000) were for short-term operation
- Before treatment costs were approximately $58,000 (including mobilization and preparatory work, site work, and solids collection and containment)
- After treatment costs were approximately $9,800 for demobilization

Description:
From 1948 to 1978, the Brown Wood Preserving site was used to pressure treat lumber products with creosote. While pentachlorophenol was occasionally used, creosote was the primary wood preservative. Lumber was pressure treated in two cylinders and wastewaters from these cylinders were discharged to a lagoon. The lagoon and soils at the site were determined to be contaminated with high levels of organics (primarily polynuclear aromatic hydrocarbons (PAHs) found in creosote) and the site was placed on the NPL in December 1982. In April 1988, following the completion of several interim removal activities, a Record of Decision (ROD) was signed specifying land treatment for contaminated soils stockpiled during the interim removal activities.

Land treatment of the PAH-contaminated soils was performed from January 1989 to July 1990. Approximately 8,100 cubic yards of stockpiled soil were treated in three lifts. The cleanup goal specified in the ROD was 100 mg/kg for Total Carcinogenic Indicator Chemicals (TCICs - the sum of the concentrations of six PAHs selected by EPA based on the results of a risk assessment) to be achieved within two years of operation. The cleanup goal was achieved within 18 months using land treatment, 6 months ahead of the 2-year timeframe specified in the ROD. The concentrations of TCICs measured during verification sampling (July 1990) ranged from 23 to 92 mg/kg. The LTA was revegetated in October 1991 and approximately 90% of the former LTA was covered with native grasses by March 1992.

The total treatment cost for this application at the Brown Wood site was approximately $565,400. The treatment costs included solids preparation and handling, mobilization and setup, and operation costs. In addition, there were before-treatment costs (mobilization and preparatory work, site work, and solids collection and containment) of approximately $58,000 and after-treatment costs (demobilization) of approximately $9,800. This application is notable for being one of the early applications of land treatment of creosote-contaminated soil at a Superfund site.

COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for a land treatment application at the Brown Wood Preserving Superfund site, located approximately two miles west of the city of Live Oak in Suwanee County, Florida. From 1948 to 1978, several different companies operated a lumber treatment facility at the site, which pressure treated lumber products mainly with creosote, and occasionally with pentachlorophenol. Soil at the site was found to have been contaminated with polynuclear aromatic hydrocarbons (PAHs).

After completion of several interim removal activities at the site, a Record of Decision (ROD) was signed on April 8, 1988. The ROD specified the construction, operation, and maintenance of a land treatment area (LTA) as the remedial action for treatment of PAH-contaminated soils that were stockpiled during the removal activities. The ROD required that, within two years, the concentrations of Total Carcinogenic Indicator Chemicals (TCICs) in the soil must be reduced to below 100 mg/kg. The concentration of TCICs was measured as the sum of the concentrations of six PAHs, which were selected by EPA based on the results of a risk assessment.

Construction of the LTA was completed in October 1988. Stockpiled soil was placed in the LTA in three lifts, beginning in January 1989. Approximately 8,100 cubic yards of stockpiled soil were treated in the LTA. Using this land treatment application, the cleanup goal of less than 100 mg/kg TCICs in soil was achieved within 18 months, six months ahead of the two-year limit specified in the ROD. The LTA was revegetated in October 1991 and approximately 90% of the former LTA was covered with native grasses by March 1992.

This application is of note as it was one of the early applications of land treatment at a Superfund site contaminated with creosote compounds.

The total costs for treatment activities at this site were approximately $565,409, over half of which were for short-term (up to 3 years) operation.

SITE INFORMATION

Identifying Information

Brown Wood Preserving Superfund Site
Live Oak, Florida
CERCLIS # FLD980728935
ROD Date: 8 April 1988

Treatment Application

Type of Action: Remedial
Treatability Study Associated with Application? Information not available at this time.
EPA SITE Program Test Associated with Application? No
Period of Operation: 1/89 - 7/90
Quantity of Soil Treated During Application: 8,100 cubic yards of soil

Background

Historical Activity That Contributed to Contamination at the Site: Wood preserving

Corresponding SIC Codes: 2491B (Wood Preserving using Creosote)

Waste Management Practice that Contributed to Contamination: Manufacturing process

Site History: The Brown Wood Preserving Superfund Site (Brown Wood) is located about two miles west of the city of Live Oak in Suwanee County, Florida, as shown in Figure 1. From 1948 to 1978, a lumber treatment facility was operated at the site by several companies. The layout of the facility is shown in Figure 2. [3]

SITE INFORMATION (CONT.)

Background (cont.)

The lumber treatment processes at the site included the pressure treatment of lumber products, mainly with creosote and occasionally with pentachlorophenol. Small rail cars were used to move lumber to the two treatment cylinders. A mixture of creosote and water or pentachlorophenol and petroleum was used to treat the lumber.

Wastewater from the treatment cylinders was discharged to an oil/water separator. The creosote from the oil/water separator was either sent to a storage tank for reuse, or, if determined to be off-specification, sent to the spent creosote storage tank. The wastewater from the oil/water separator was treated and discharged to a lagoon located in the southwest corner of the site via a culvert and drainage ditch. The treated lumber was dried on rail tracks and stored in an area north of the treatment cylinders. [1]

In 1981, a former owner of the facility notified EPA that hazardous materials may have been handled at the site. As a result, the Florida Department of Environmental Regulations (FDER) conducted sampling at the site in July 1982, which showed that soil and sludge contaminated with a number of organic compounds were present in the area of the treatment cylinders and the lagoon. Additionally, the storage tanks and treatment cylinders contained small amounts of solidified creosote and pentachlorophenol. Based on these results, EPA placed the site on the National Priorities List in December 1982. [1]

In response to an administrative order issued by EPA in September 1983, interim removal activities were identified and specified in a January 1988 Consent Order. [1] The interim removal activities, conducted from December 1987 to March 1988, included:

- Removal and treatment of 200,000 gallons of lagoon water, using flocculation, sand filtration, micron filtration, and carbon adsorption, and dismantling and disposing of the former plant facility;

Figure 1. Site Location

- Excavation, treatment (using stabilization), and disposal of approximately 15,000 tons of highly contaminated sludge and soil at an Emelle, Alabama, landfill operated by Chemical Waste Management; and

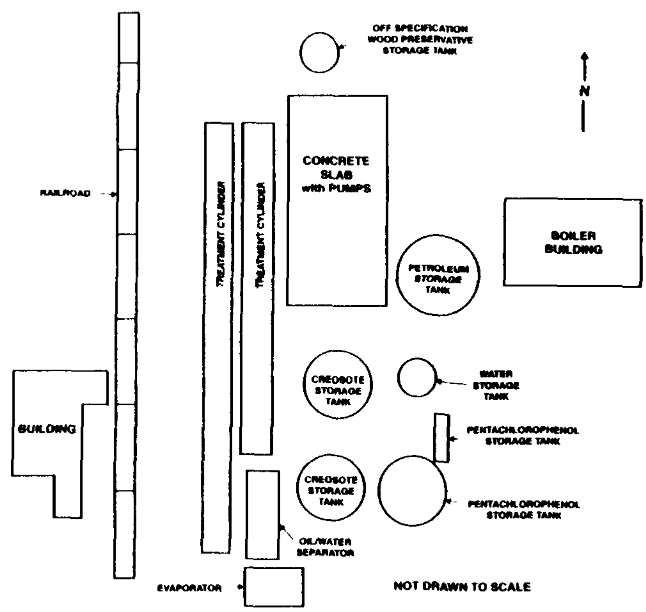

Figure 2. Site Layout [3]

SITE INFORMATION (CONT.)

Background (cont.)

- Sampling and analysis of soil and water and stockpiling contaminated soil for land treatment.

Regulatory Context: The 1988 ROD established a cleanup goal of 100 mg/kg of Total Carcinogenic Indicator Chemicals (TCICs) for the stockpiled soil based on land treatment. The concentration of TCICs was measured as the sum of the concentrations of six PAHs, which were selected by EPA based on the results of a risk assessment. [1]

Remedy Selection: The following remedial action alternatives were considered for the Brown Wood Preserving Superfund site [1]:

- No action;
- On-site incineration;
- Off-site incineration;
- Land treatment;
- Treatment (mechanical or stabilization) of sludge and off-site disposal of wastes;
- Treatment (mechanical or stabilization) and disposal of sludges and land treatment of soils; and
- Biological treatment of sludges using sequenced batch reactors followed by land treatment of the resulting biosludge and the contaminated soils.

Land treatment of soils was selected by EPA as a remedial action for Brown Wood based on cost and technical feasibility. Additionally, this remedy provided an opportunity to utilize and assess an innovative technology/bioremediation in a controlled situation. [1,5]

Site Logistics/Contacts

Site Management: PRP Lead
Oversight: EPA

Remedial Project Manager:
Martha Berry
U.S. EPA Region 4
345 Courtland St., N.E.
Atlanta, Georgia 30365
(404) 347-3016

Treatment System Vendor:
John Ryan
Remediation Technologies, Inc. (ReTeC)
1011 Southwest
Klickitat Way
Suite 207
Seattle, WA 98134
(206) 624-9349

MATRIX DESCRIPTION

Matrix Identification

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

Contaminant Characterization

Primary contaminant group: Polynuclear aromatic hydrocarbons (PAHs)

Creosote was the main contaminant at the site. Creosote consists of approximately 200 individual compounds, many of which are polynuclear aromatic hydrocarbons (PAHs). Six of these PAHs [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene] were selected by EPA as indicator parameters based on the results of a risk assessment. The total concentrations of these parameters in the stockpiled soil ranged from 100 to 208 mg/kg. [1,8]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Cost or Performance

The major characteristics affecting cost or performance of this technology and the values measured for each are presented in Table 1. These values represent the average values measured during a March 1, 1989 sampling event.

Table 1. Matrix Characteristics [11, 12]

Parameter	Value	Measurement Method
Soil classification	See discussion below	—
Clay content and/or particle size distribution	See discussion below	—
Field capacity	Not Available	—
pH	6.9	USEPA Method SW-846/9045
Total Organic Carbon	11,790 mg/kg	USEPA Method SW-846/9060

The matrix treated at Brown Wood was a mixture of lagoon contents. The lagoon had a clay bottom and sandy contents, which ranged from silty clay to fine sand, but did not lend itself to a classification analysis. [21]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology Type

Land Treatment

Supplemental Treatment Technology Type

None

Land Treatment System Description and Operation

Construction of the land treatment area (LTA) involved site preparation, construction of the components of the LTA, construction of a retention pond, and installation of irrigation and drainage systems. The locations of the land treatment area, stockpile area, retention pond, and lagoon are shown in Figure 3. [12]

Site preparation activities included clearing vegetation and structures from approximately four acres. An estimated 200 yds^3 of contaminated soil were excavated during the site preparation activities and stored in the central stockpile area. [2]

The construction of the LTA included [2]:

- A clay liner, which ranged from 1 to 3 feet in thickness.
- A compacted clay berm around the LTA that ranged in height from 2.5 to 7 feet and a 3-foot berm around the soil stockpile area.

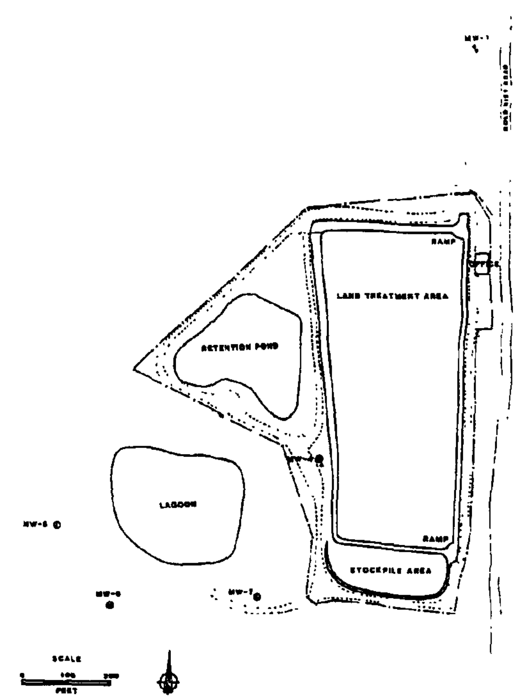

Figure 3. Land Treatment Area Location [12]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Land Treatment System Description and Operation (cont.)

- Run-on swales outside the treatment area to prevent flowing surface water from entering the site.
- A subsurface drainage system consisting of lateral pipes spaced 50 feet apart across the treatment area connected to a main collector pipe. The sump drained through a 15-inch pipe into the retention pond.
- A 750,000-gallon retention pond to hold run-off from the LTA that included an overflow line to an on-site, clay-lined lagoon.
- A portable irrigation system consisting of individual sprinkles capable of delivering water at 0.5 inches per hour to a diameter of 70 feet. The system used water from either the retention pond or the lagoon.

System Operation: Land treatment was performed in three lifts. For sampling purposes, the LTA was divided into eight half-acre subplots, as shown in Figure 4. [10] A composite sample was collected from each subplot, during each quarterly sampling event, until the concentrations of TCICs contained in the soil within the subplot was less than 100 mg/kg. [1,8] An additional lift of soil from the stockpile area was then placed in the subplot and treated until the concentrations of TCICs in the soil were less than 100 mg/kg. This process was continued until all of the stockpiled soil had been treated. The three lifts are described below:

- The first lift was placed into the LTA in January 1989. This lift was approximately 3,300 yds^3 of soil and 5 to 7 inches thick. This lift was cultivated to a depth of approximately 1 foot, then irrigated and fertilized. Twice a week, from March 1, 1989 until March 15, 1989, the soil in the LTA was inoculated with PAH-degrading microorganisms. [19] The inoculum was developed by growing seed cultures in mobile, on-site reactor tanks equipped with aeration and mixing equipment and was sprayed onto the soil using the irrigation system described above. The land treatment area was then cultivated once every two weeks and maintained at a 10% soil moisture content level using the irrigation system. Samples were collected on 3/1/89, 6/6/89, and 9/12/89. [2,19]
- The second lift of soil was applied to Subplots A, B, D, E, F, G, and H of the LTA on September 12, 1989. The lift

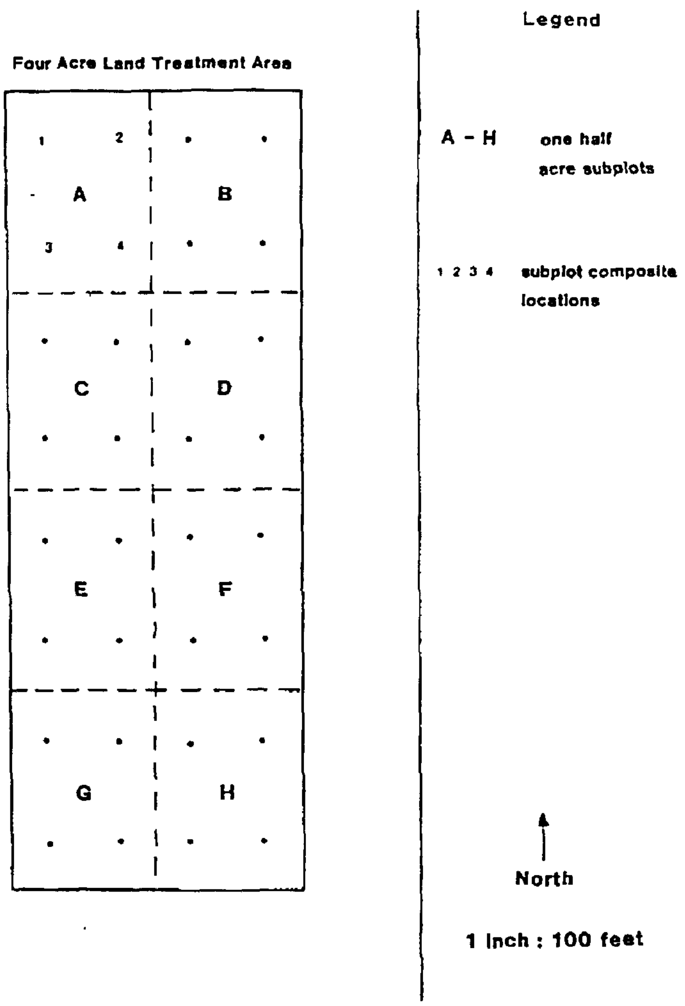

Figure 4. Subplot Locations [10]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Land Treatment System Description and Operation (cont.)

was 9 to 12 inches thick and included approximately 3,000 yd^3 of soil. As with Lift 1, the LTA was then cultivated once every two weeks and the moisture content maintained at 10 percent. Samples were collected on 9/16/89 and 12/15/89. [2,19]

- The third lift of soil was applied to Subplots C through H of the LTA. This lift was 4 to 7 inches thick and included approximately 1,800 yd^3 of soil. As with the previous lifts, the LTA was cultivated once every two weeks and the moisture content maintained at 10 percent. Samples were collected on 3/15/90 and 7/24/90. [2,3,11,12]

One problem encountered during system operation was tilling the soil after heavy rains. Soil drying normally took an average of 2 weeks before tractor access was possible. [21]

Level D personal protective equipment was required for all site personnel coming into direct contact with the contaminated soil. The equipment included coveralls, safety boots, nitrile gloves, and particulate masks. [9]

Operating Parameters Affecting Treatment Cost or Performance

Listed in Table 2 are the operating parameters affecting treatment cost or performance for this application and the values measured for each. The following operating parameters are presented separately for each lift:

- Total heterotrophs;
- PAH degraders;
- Mixing rate/frequency;
- Moisture content;
- pH;
- Residence time;
- Temperature;
- Carbon/total kjeldahl nitrogen; and
- Hydrocarbon degradation.

Hydrocarbon degradation was calculated based on the difference in initial and final TCIC concentrations in the first lift and dividing this value by the amount of time required for treatment of soil in that cell in the first lift.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Table 2. Operating Parameters [10-17, 19, 20]

Parameter	Value								Measurement Method
	Subplot								
	A	B	C	D	E	F	G	H	
First Lift of Soil (a)									
Total Heterotrophs (cfu/gm)	6.4×10^6 - 7.4×10^6	1.1×10^7 - 1.6×10^7	7×10^5 - 9.9×10^7	4.1×10^6 - 2.7×10^7	1.5×10^7 - 7.8×10^7	1.0×10^7 - 4.3×10^7	1.9×10^7 - 4.3×10^7	1.8×10^7 - 4.6×10^7	(b)
PAH Degraders (cfu/gm)	1.0×10^5 - 5.0×10^7	3.0×10^5 - 2.2×10^7	1.0×10^5 - 5.7×10^6	2.0×10^5 - 7.2×10^6	2.8×10^6 - 1.9×10^7	1.4×10^6 - 5.7×10^6	3.6×10^6 - 1.5×10^7	3.2×10^6 - 3.0×10^7	(c)
Mixing Rate/Frequency	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	--
Moisture Content (%)	7.7 to 8.8	8.1 to 9.6	10.3 to 10.5	9.3 to 9.5	12.4 to 22.8	11.0 to 11.9	11.2 to 12.5	12.4 to 13.2	Not available
pH	6.8	6.8 to 7.2	7.0 to 7.7	6.6 to 7.2	6.7 to 6.8	6.8 to 7.1	6.4 to 6.8	6.5 to 6.7	USEPA Method SW-846/9045
Residence Time (months)	9	9	15	9	9	9	9	9	--
Temperature (°F)	17 to 99	17 to 99	13 to 99	17 to 99	17 to 99	17 to 99	17 to 99	17 to 99	Thermometer (d)
Carbon/Total Kjeldahl Nitrogen	10.3	15.4	9 to 11.0	10.1	8.8	11.5	13.2	14.2	Not available
Hydrocarbon Degradation (mg/kg/mo)	58	18	13	38	28	20	38	38	Calculated value
Second Lift of Soil (a)									
Total Heterotrophs (cfu/gm)	6.3×10^5 - 6.6×10^7	1.7×10^5 - 1.3×10^7	N/A	1.8×10^7	1.3×10^7 - 8.4×10^7	1.2×10^7 - 2.5×10^7	3.8×10^7	2.3×10^7	(b)
PAH Degraders (cfu/gm)	7.0×10^2 - 4.5×10^6	2.0×10^3 - 6.0×10^5	N/A	9.0×10^5	2.5×10^6 - 6.2×10^6	3.1×10^6 - 1.7×10^7	4.2×10^6	5.5×10^6	(c)
Mixing Rate/Frequency	Tilled once every 2 wks	Tilled once every 2 wks	N/A	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	--
Moisture Content (%)	10.3 to 15.4	12.0 to 11.6	N/A	12.4	12.9 to 21.1	14.5 to 19.0	14.8	12.9	Not available
pH	6.7 to 7.3	6.8 to 7.5	N/A	7.6	7.6	6.8 to 7.6	7.6	7.8	USEPA Method SW-845/9045
Residence Time (months)	10	10	N/A	6	6	6	6	6	--
Temperature (°F)	13 to 102	13 to 102	N/A	13 to 94	13 to 94	13 to 94	13 to 94	13 to 94	Thermometer (d)
Carbon/Total Kjeldahl Nitrogen	25 to 36	15 to 20	N/A	78	8.8 to 15.0	11.0 to 32.0	46	18	Not available

TREATMENT SYSTEM DESCRIPTION (CONT.)

Table 2 (continued). Operating Parameters [10-17, 19, 20]

Parameter	Value								Measurement Method
	Subplot								
	A	B	C	D	E	F	G	H	
Third Lift of Soil (a)									
Total Heterotrophs (cfu/gm)	N/A	N/A	4.87×10^6- 7.90×10^6	3.20×10^6- 9.07×10^6	2.7×10^5- 7.55×10^6	7.0×10^4- 1.1×10^7	5.0×10^5- 1.39×10^7	7.0×10^5- 3.67×10^6	(b)
PAH Degraders (cfu/gm)	N/A	N/A	1.85×10^4- 4.0×10^5	1.15×10^4- 3.0×10^5	5.5×10^3- 4.0×10^5	2.75×10^4- 3.0×10^5	7.5×10^3- 4.90×10^6	2.95×10^4- 8.0×10^5	(c)
Mixing Rate/Frequency	N/A	N/A	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	Tilled once every 2 wks	--
Moisture Content (%)	N/A	N/A	12.6 to 16.3	13.9 to 14.6	8.5 to 14.7	9.4 t 13.9	8.9 to 14.0	8.9 to 14.2	Not available
pH	N/A	N/A	6.4 to 7.0	6.5 to 6.8	6.6 to 6.9	6.7 to 6.9	6.7 to 7.0	6.7 to 7.0	USEPA Method SW-846/9045
Residence Time (months)	N/A	N/A	4	4	4	4	4	4	--
Temperature (°F)	N/A	N/A	29 to 102	29 to 102	29 to 102	29 to 102	29 to 102	29 to 102	Thermometer (d)
Carbon/Total Kjeldahl Nitrogen	N/A	N/A	30 to 37	15 to 58	20 to 31	43 to 67	6 to 51	30 to 32	Not available

N/A - This lift of soil was not applied to this subplot.

(a) - The values for each lift of soil are ranges of values measured in samples collected from the time that the lift was applied to the subplot until the next lift of soil was applied to the subplot.

(b) - "Agar-Plate Method for Total Microbial Count," F. Clark, Methods of Soil Analysis, Vol. 2, pp. 1460-1465.

(c) - "Replica Plating Method for Estimating Phenanthrene-Utilizing and Phenanthrene-Cometabolizing Microorganisms," Shiaris, M., Cooney, J., Applied and Environmental Microbiology, February 1983, Vol. 45, No. 2, pp. 706-710.

(d) - These values are for the ambient air temperatures measured between application of lifts.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Timeline

A timeline for this application is presented in Table 3.

Table 3. Timeline [10-17,19,20]

Start Date	End Date	Activity
December 8, 1983	—	Brown Wood added to National Priorities List.
December 1987	March 1988	Interim removal actions conducted at the site.
April 18, 1988	—	ROD signed.
October 1988	January 1989	Remedial action construction activities completed.
January 1989	—	First lift of soil applied to all subplots.
March 1, 1989	March 15, 1989	Soil inoculated with PAH-degrading microorganisms at a frequency of two applications per week.
March 1, 1989	—	Soil sampled and analyzed for PAHs and nutrients.
June 6, 1989	—	Soil sampled and analyzed for PAHs and nutrients.
September 12, 1989	—	Soil from Subplots C and D sampled and analyzed for PAHs. Cleanup goal met for all subplots except Subplot C.
September 15, 1989	—	Second lift of soil applied to all subplots except Subplot C.
September 16, 1989	—	Soil from all subplots except Subplot C sampled and analyzed for PAHs and nutrients Cleanup goal met for all subplots except Subplots E and F.
December 15, 1989	—	Soil from Subplots C, E, and F sampled and analyzed for PAHs and nutrients. Cleanup goal met for all subplots.
March 14, 1990	—	Third lift of soil (remaining soil in the stockpile area) applied to Subplots C through H.
March 15, 1990	—	Soil from Subplots C through H sampled and analyzed for PAHs and nutrients.
July 24, 1990	—	Soil from all subplots sampled and analyzed for PAHs and nutrients. Cleanup goal met for all subplots.
January 1991	—	Target date for completion.
June 1991	—	Cultivation of the LTA completed
November 1991	—	Vegetative cover planted over LTA.
March 1992	—	Ninety percent of LTA covered with grass

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals Standards

The ROD specified cleanup goals for polynuclear aromatic hydrocarbons in terms of total carcinogenic indicator chemicals (TCICs). TCICs were defined as equal to the sum of the concentrations of the following six polynuclear aromatic hydrocarbons:

- Benzo(a)anthracene;
- Benzo(a)pyrene;
- Benzo(b)fluoranthene;
- Chrysene;
- Dibenzo(a,h)anthracene; and
- Indeno(1,2,3-cd)pyrene.

These indicator chemicals were selected by EPA based on their concentrations in sludge and soil at the site and their carcinogenic nature. [1]

The ROD required that within two years from its initial seeding, the land treatment process must reduce the concentration of TCICs to 100 mg/kg throughout the volume of the material treated (based on quarterly sampling results), and that, upon successful completion of the bioremediation in the land treatment area, the land treatment area must be revegetated. [1,8]

TREATMENT SYSTEM PERFORMANCE (CONT.)

Additional Information on Goals

The 100 mg/kg cleanup standard for TCICs was based on the results of a risk assessment for the site. This level corresponds to a 1 x 10^{-6} soil ingestion risk level. [1]

Treatment Performance Data [10, 11, 12, and 20]

Composite samples were collected from each half-acre subplot, as described earlier in this report. These samples were analyzed for PAHs using EPA Method 8270. [9,10] Table 4 shows the concentrations of TCICs measured in the seven sampling events during the bioremediation of soils at Brown Wood. Samples collected on 12/15/89 and 7/24/90 were collected after cultivating the soil lift with previously applied lifts. Analytical results for individual PAH constituents are presented in Appendix A.

Table 4. TCIC Concentrations [9, 10, 11, 12, 20]

		TCIC Concentration (mg/kg)							
		Subplot							
Date	Event	A	B	C	D	E	F	G	H
January 1989	Soil application* (Lift #1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
March 1, 1989	Soil sampling	258	103	201	255	161	126	186	167
June 6, 1989	Soil sampling	73	46	147	478	73	63	65	45
September 12, 1989	Soil sampling	NA	NA	120	1 5	NA	NA	NA	NA
September 15, 1989	Soil application (Lift #2)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
September 16, 1989	Soil sampling	71	95	NA	44	111	111	49	88
December 15, 1989	Soil sampling	NA	NA	72	NA	18	41	NA	NA
March 14, 1990	Soil application (Lift #3)	No	No	Yes	Yes	Yes	Yes	Yes	Yes
March 15, 1990	Soil sampling	NA	NA	25	36	59	57	51	54
July 24, 1990	Soil sampling	59	75	77	92	57	34	23	27

**No samples were collected from lift #1 at the time of soil application. A TCIC concentration of 100 to 208 mg/kg was measured in the stockpiled soils prior to soil application.*
NA - Not analyzed.

Performance Data Assessment

The land treatment application at Brown Wood met the cleanup goal for TCICs in all 8 subplots, within 18 months. The data indicate that biodegradation rates differed among the subplots. For example, Subplot A achieved the cleanup goal in LTA #1 sooner (i.e., within 3 months) than in Subplot C (i.e., within 9 months).

The land treatment application at Brown Wood was conducted in 3 lifts, and the data assessment is presented below for each lift.

Lift #1: An assessment of the data presented in Table 4 indicates that the concentrations of TCICs in the samples collected during the first sampling event (3/1/89), after the first soil lift was applied, ranged from 103 to 258 mg/kg. The concentrations of TCICs in each subplot measured in samples collected on 3/1/89 was greater than the 100 mg/kg level. The concentrations of TCICs measured during the 6/6/89 sampling event were less than the 100 mg/kg level in all subplots except Subplots C and D. The concentrations of TCICs measured during a 9/12/89 sampling event showed that the 100 mg/kg level had been achieved for Subplot D, but not for Subplot C. The concentration of TCICs measured in the sample collected on 12/15/89 from Subplot C was less than the 100 mg/kg level.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (cont.)

An assessment of the relative rates of biodegradation among the subplots for Lift #1 indicates that rates varied from as high as a 58 mg/kg decrease per month (e.g., for Subplot A) to as low as a 13 mg/kg decrease per month (e.g., for Subplot C).

Lift #2: On 9/15/89, a second lift of soil from the stockpile was applied to all subplots except Subplot C. This lift was sampled on 9/16/89 prior to tilling. The results from the 9/16/89 sampling event indicated that the concentrations of TCICs in all subplots except Subplots E and F were less than the 100 mg/kg level. Concentrations of several PAH constituents sampled on 9/16/89 were slightly higher (within a factor of 3) than those measured in samples from the 6/6/89 sampling event.

Sampling of Subplots E and F conducted on 12/15/89 indicated that the concentrations of TCICs were less than the 100 mg/kg level in all subplots of the LTA.

Lift #3: On 3/14/90, the third lift of stockpiled soil was applied to Subplots C through H of the LTA. This lift was sampled on 3/15/90 prior to tilling. The results from the 3/15/90 sampling indicated that the concentrations of TCICs in Subplots C through H were less than the 100 mg/kg level.

Verification samples were collected on 7/24/90 from all subplots. The results of this sampling event indicated that the concentrations of TCICs in all of the subplots in the LTA were less than the 100 mg/kg cleanup goal. The concentrations of TCICs measured in these samples ranges from 23 to 92 mg/kg.

Performance Data Completeness

As discussed above, although the concentrations of PAHs in the soil stockpiled for land treatment were measured during the removal activities, the initial concentrations of PAHs in the first lift applied to the LTA were not measured. Additionally, once the cleanup standard was achieved in a subplot, the subplot was not monitored further unless an additional lift of soil was applied. Therefore, the available performance data are suitable for characterizing indicator constituents in the treated soil matrix, and for correlating constituent concentrations and operating parameters.

Performance Data Quality

A rigorous quality assurance/quality control (QA/QC) program for sampling and analytical activities was outlined in the Remedial Design/Remedial Action (RD/RA) Work Plan and approved by EPA. [9] Appendices to the quarterly status and semi-annual operation and maintenance reports [10 through 17) include raw QA/QC data from the laboratory reports for each sampling event, including results for matrix spike, duplicate, and blank samples.

ReTeC conducted sampling and analysis activities over the course of the soil remediation. EPA performed oversight of sampling activities and verified analytical accuracy and precision by splitting samples during three sampling events. Deviations from the field sampling procedures outlined in the RD/RA Work Plan were observed by EPA, but none were determined by EPA to be serious enough to reject the data. The split sample results were consistent for all three sampling events. [8]

TREATMENT SYSTEM COST

Procurement Process

The remedial activities at Brown Wood were managed by the potentially responsible parties (PRPs) with EPA oversight. The PRPs contracted with ReTeC to conduct the remedial activities at the site.

Treatment System Cost

Tables 5, 6, and 7 present the costs for the land treatment application at Brown Wood. In order to standardize reporting of costs across projects, costs are shown in Tables 5, 6, and 7 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 5, 6, and 7 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 by the treatment vendor.

As shown in Table 5, the vendor provided actual and estimated cost data that shows a total of $565,406 for cost elements directly associated with treatment of 8,100 cubic yards of soil (i.e., excluding before and after treatment cost elements). This total treatment cost corresponds to $70 per cubic yard of soil treated. In addition, the vendor provided cost data that show a total of $58,039 for before-treatment costs and $9,827 for after-treatment costs. The vendor indicated that there were no costs in this application for the following elements in the WBS: surface water collection and control; groundwater collection and control; air pollution/gas collection and control; liquids/sediments/sludges collection and containment; drums/tanks/structures/miscellaneous demolition and removal; liquid preparation and handling; vapor/gas preparation and handling; pads/foundations/spill control; startup/testing/permits; training; cost of ownership; dismantling; decontamination and decommissioning; disposal (other than commercial); disposal (commercial); or site restoration. The vendor provided no information on costs for monitoring, sampling, testing, and analysis in this application. Note that the vendor provided a total cost value for mobilization and demobilization; the values shown in Tables 6 and 7 were calculated based on the assumption that these cost elements were equal in value.

Cost Data Quality

The cost data in Tables 5, 6, and 7 show estimated values for construction activities (solids preparation and handling, mobilization/setup, mobilization and preparatory work, site work, solids collection and containment, and demobilization), which are based on proposed unit prices provided by the vendor. No actual cost data are availa' le for these activities. The costs for operations and maintenance shown in Table 5 are actual costs reported by the vendor.

Vendor Input

Costs for similar operations were estimated by the treatment vendor to range from $50 to $100 per cubic yard of soil treated for quantities in excess of 3,000 cubic yards. [21]

TREATMENT SYSTEM COST (CONT.)

Treatment System Cost (cont.)

Table 5. Treatment Cost Elements [21]

Cost Element	Cost	Actual (A) or Estimated (E) Value
Solids Preparation and Handling		
- spreading of contaminated soil $2.77/yd^3 x 3,200 yd^3	$8,864	E
Mobilization/Setup		
- installation of clay liner $3.23/yd^3 x 7,000 yd^3	$22,610	E
- installation of subsurface drainage network lump sum	$68,062	E
- construction of perimeter containment berms $3.29/ft x 2,000 ft	$6,580	E
- shape retention pond lump sum	$3,293	E
- installation of runon drainage swales $1.15/ft x 3,000 ft	$3,450	E
- installation of irrigation system lump sum	$20,312	E
Operation (short-term - up to 3 years)		
- 1988 O&M (construction management)	$36,883	A
- 1989 O&M (includes approximately $40,000 for groundwater monitoring)	$194,118	A
- 1990 O&M (includes approximately $40,000 for groundwater monitoring)	$80,560	A
Operation (long-term - over 3 years)		
- 1991 O&M (groundwater monitoring and site restoration)	$60,477	A
- 1992 O&M (groundwater monitoring and site restoration)	$37,307	A
- 1993 O&M (groundwater monitoring and site restoration)	$22,891	A
TOTAL	**$565,406**	**E**

Table 6. Before Treatment Cost Elements [21]

Cost Element	Cost	Actual (A) or Estimated(E) Value
Mobilization and Preparatory Work		
- mobilization of equipment, material, and personnel lump sum	$9,827	E
Site Work		
- site preparation $4,781.17/acre x 5 acres	$23,906	E
- fence lump sum	$22,610	E
Solids Collection and Containment		
- stockpile remaining soil $0.53/yd^3 x 3,200 yd^3	$1,696	E

Table 7. After Treatment Cost Elements [21]

Cost Element	Cost	Actual (A) or Estimated (E) Value
Demobilization		
- demobilization of equipment, material, and personnel lump sum	$9,827	E

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- The total costs for treatment activities conducted at Brown Wood were approximately $565,400, corresponding to $70 per cubic yard of soil treated.
- The treatment at Brown Wood was completed using 3 lifts; the system was constructed using a clay liner and underdrain system.
- Over half of the total costs for treatment were for short-term (up to 3 years) operation.
- Other costs in this application were $58,039 for before-treatment activities and $9,827 for after-treatment activities.

Performance Observations and Lessons Learned

- The cleanup goal was established in terms of Total Carcinogenic Indicator Compounds (TCICs), the sum of the concentrations of 6 polynuclear aromatic hydrocarbons. A cleanup goal for this application was specified as 100 mg/kg TCICs in the LTA.
- The cleanup goal was achieved within 18 months, which was approximately 6 months ahead of the 2-year limit specified in the ROD.
- The concentrations of TCICs measured in samples collected during the verification sampling event (7/24/90) ranged from 23 to 92 mg/kg.
- Biodegradation rates were found to have varied among the eight subplots. During treatment of one lift, rates varied from 13 to 58 mg/kg decreases in TCIC concentration per month.
- The treated soil in the LTA was capable of supporting vegetation.

Other Observations and Lessons Learned

- This was one of the early applications of land treatment of creosote-contaminated soil 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 Corporation under EPA Contract No. 68-W3-0001.

APPENDIX A—INDIVIDUAL PAH ANALYTICAL RESULTS [10-17, 19, 20]

Constituent	Sample Date(a)	Concentration in mg/kg Subplot A	B	C	D	E	F	G	H
Chrysene	03/01/89	79.0	33.0	53.0	70.0	48.0	39.0	57.0	50.0
	06/06/89	21.0	12.0	43.0	150.0	22.0	17.0	19.0	13.0
	09/12/89	NA	NA	36.9	2.6	NA	NA	NA	NA
	09/16/89	22.0	30.0	NA	14.0	37.0	38.0	15.0	26.0
	12/15/89	NA	NA	31.5	NA	18.0	23.5	NA	NA
	03/15/90	NA	NA	8.9	12.0	22 0	21 0	17.0	20.0
	07/24/90	19.0	26.0	27.0	35.0	18.0	9.5	4.5	6.9
Benzo(a)anthracene	03/01/89	110.0	36.0	70.0	93.0	60.0	50.0	81.0	71.0
	06/06/89	17..0	10.0	46.0	180.0	23.0	17.0	16.0	12.0
	09/12/89	NA	NA	31.9	2.2	NA	NA	NA	NA
	09/16/89	24.0	30.0	NA	13.0	38.0	35.0	14.0	25.0
	12/15/89	NA	NA	22.5	NA	ND (12.5)	17.0	NA	NA
	03/15/90	NA	NA	5.8	7.5	16.0	13.0	11.0	12.0
	07/24/90	11.0	18.0	18.0	23.0	12.0	5.9	5.2	4.1
Benzo(b)fluoranthene	03/01/89	41.0	16.0	48.0	55.0	27.0	18.0	27.0	24.0
	06/06/89	20 0	13.0	36.0	98.0	17.0	15 0	16.0	12.0
	09/12/89	NA	NA	31.0	5.1	NA	NA	NA	NA
	09/16/89	14.0	22.0	NA	11.0	23.0	23.0	13.0	22.0
	12/15/89	NA	NA	18.0	NA	ND (12.5)	ND (12.5)	NA	NA
	03/15/90	NA	NA	6.7	8.2	10.0	12.0	12.0	11.0
	07/24/90	14.0	15.0	16.0	17.0	12.0	8.1	6.6	6.8
Benzo(a)pyrene	03/01/89	17.0	11.0	20.0	17.0	12.0	14.0	14.0	14.0
	06/06/89	8.2	6.5	14.0	7.5	10.0	10.0	6.2	6.2
	09/12/89	NA	NA	11.6	NA	NA	NA	NA	NA
	09/16/89	8.4	13.0	NA	13.0	15.0	7.4	11.0	11.0
	12/15/89	NA	NA	ND (17.0)	ND (17.5)	ND (17.5)	NA	NA	NA
	03/15/90	NA	NA	3.5	7.1	6.9	6.5	6.5	7.3
	07/24/90	7.7	8.9	10.0	7.0	5.0	3.0	3.0	5.0
Dibenzo(a,h)anthracene	03/01/89	2.9	1.8	2.4	3.2	2.5	1.8	1.9	2.0
	06/06/89	NA (0.9)	ND (0.9)	ND (0.9)	3.5	ND (0.9)	ND (0.9)	ND (0.9)	ND (0.9)
	09/12/89	BA	NA	ND (1.8)	ND (1.8)	NA	NA	NA	NA
	09/16/89	ND (1.8)	ND (3.6	NA	ND (3.7)	ND (3.7)	ND (3.7)	ND (1.9	ND (1.8)
	12/15/89	NA	NA	ND (19.5)	NA	ND (20.5)	ND (20.0)	NA	NA
	03/15/90	NA	NA	ND (1.8	ND (1.9)	ND (1.7)	ND (1.8)	ND (1.8	ND (1.8)
	07/24/90	ND (1.9)	ND (1.8)	ND (1.9)	ND (1.9)	1.6	1.2	0.4	ND (0.9)
Indeno(1,2,3-cd)pyrene	03/01/89	7.7	5.3	7.6	11.0	6.0	5.3	4.9	5.7
	06/06/89	5.7	5.7	7.4	13.0	2.8	3.3	2.7	0.9
	09/12/89	NA	NA	8.7	2.1	NA	NA	NA	NA
	09/16/89	3.0	ND (3.6)	NA	ND (3.7)	ND (3.7)	ND (3.7)	ND (1.9)	4.4
	12/15/89	NA	NA	ND (19.5)	NA	ND (20.5)	ND (20.0)	NA	NA
	03/15/90	NA	NA	ND (1.8)	2.7	3.6	3.8	4.0	3.6
	07/24/90	7.6	7.5	6.4	7.4	6.1	4.7	2.8	4.2
TCIC(b)	03/01/89	258	103	201	255	161	126	186	167
	06/06/89	73	46	147	478	73	63	65	45
	09/12/89	NA	NA	120	15	NA	NA	NA	NA
	09/16/89	71	95	NA	44	111	111	49	88
	12/15/89	NA	NA	72	NA	18	41	NA	NA
	03/15/90	NA	NA	25	36	59	57	51	54
	07/24/90	59	75	77	92	57	34	23	27

ND - Not detected. Number in parentheses is the minimum quantitation limit.

NA - Sample was not collected from this subplot since the concentration of TCICs in the sample collected during the previous sampling event was less than the 100 mg/kg cleanup standard.

(a) Second and third lifts of soil had been applied to the LTA prior to the 09/16/89 and 03/15/90 sampling events, respectively. The second lift of soil was applied to all subplots, except Subplot C. The third lift of soil was applied to all subplots, except Subplots A and B.

(b) TCIC equals sum of concentrations for chrysene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

Refueling Loop E-7, Source Area ST20
Bioventing Treatment at Eielson Air Force Base
Alaska
(Interim Report)

Case Study Abstract

Refueling Loop E-7, Source Area ST20
Bioventing Treatment at Eielson Air Force Base, Alaska

Site Name: Eielson Air Force Base Source Area ST20	**Contaminants:** Total Petroleum Hydrocarbons (TPH) and Benzene, Toluene, Ethylbenzene, Xylenes (BTEX) - Soil TPH levels averaged 1,500 mg/kg - Contamination is concentrated in areas greater than 5.25 feet below ground surface	**Period of Operation:** Status - Ongoing Report covers - 7/91 to 7/94
Location: Fairbanks, Alaska		**Cleanup Type:** Field Demonstration
Vendor: Ronald M. Smith Battelle-Pacific Northwest Labs Richland, WA	**Technology:** Bioventing - Bioventing conducted in conjunction with several soil warming techniques - Four experimental plots tested: passive warming, active warming, surface warming, and control	**Cleanup Authority:** CERCLA and State: Alaska - Federal Facilities Agreement - ROD Date: 9/92
SIC Code: 9711 (National Security)		**Point of Contact:** Capt. Timothy Merrymon 354 CES/CEVR 2258 Central Ave., Suite 1 Eielson AFB, Alaska 99702
Waste Source: Spills and Leaks of JP-4 Jet Fuel	**Type/Quantity of Media Treated:** Soil - Thickness of contamination in saturated zone - 6.1 meters - Soil consists of interbedded layers of loose to medium dense gravel and sands with varying amounts of silt to 6-9 feet - Underlain by 600 feet of medium dense to dense sandy gravel - No permafrost encountered at site	
Purpose/Significance of Application: Bioventing with various soil warming techniques to demonstrate technology effectiveness in a subarctic environment.		

Regulatory Requirements/Cleanup Goals:
- TPH - 200 mg/kg in soil
- Benzene - 2 lbs/day in extracted soil gas
- Remedial activities to be conducted in accordance with a Federal Facilities Agreement between U.S. Air Force, U.S. EPA, and the Alaska Department of Environmental Conservation

Results:
- Bioventing project not complete at time of this report
- Preliminary results indicate that bioventing with soil warming stimulates in situ biodegradation year round in a subarctic environment
- Active warming achieved higher biodegradation rates than passive or surface warming
- Ambient air samples showed no detectable concentrations of benzene 4 feet and 6 feet above ground level

Cost Factors:
- Estimated Capital Costs - $758,077 (including floating fuel collection devices, soil bioventing equipment, composting site development, mobilization, groundwater remediation and engineering design)
- Estimated Annual Operations and Maintenance (O&M) Costs - $177,160 (O&M of three components - floating fuel (5 year duration), soil bioventing (10 year duration), groundwater monitoring (30 year duration), including sample analysis and monitoring of each component)

Refueling Loop E-7, Source Area ST20
Bioventing Treatment at Eielson Air Force Base, Alaska (Continued)

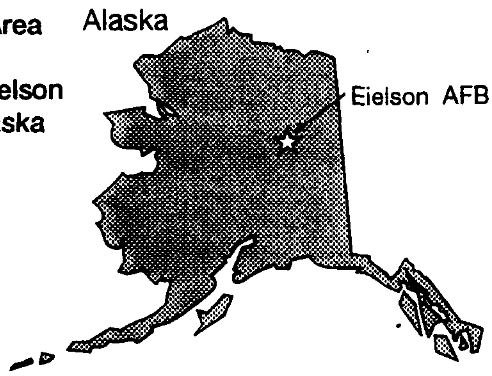
Description:
As a result of spills and leaks of JP-4 jet fuel at a refueling complex at Eielson Air Force Base (AFB) in Fairbanks, Alaska, soil was contaminated with total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylenes (BTEX). In November 1989, Eielson AFB was added to the National Priorities List (NPL) with the fuel-saturated area within the Refueling Loop E-7, Source Area ST20 designated as CERCLA Operable Unit 1. A field demonstration of bioventing and three soil warming techniques began in July 1991 including active warming, passive warming, and surface warming. Specific cleanup goals include TPH (200 mg/kg in soil), and benzene (2 lbs/day in extracted soil gas).

The field demonstration of the bioventing system was on-going as of July 1994. Available respiration test data for oxygen consumption rates confirmed the occurrence of biological degradation processes. Preliminary results indicate that bioventing with soil warming achieves biodegradation year round in a subarctic environment. Active warming was found to achieve a higher biodegradation rate than passive or surface warming. It was noted that biodegradation is enhanced by adequate soil oxygen, moisture, and nutrient levels; that injection wells are impractical at source areas with a naturally high concentration of iron in the groundwater; and that high soil moisture content interferes with soil gas monitoring and reduces the number of soil gas monitoring points that can be sampled.

The estimated capital cost of this application was approximately $758,000 and the estimated annual operations and maintenance costs are $177,160. Full-scale remedial activities at the site will be conducted in accordance with a Federal Facilities Agreement between the U.S. Air Force, U.S. EPA, and the Alaska Department of Environmental Conservation.

SITE

Refueling Loop E-7 Complex, Source Area ST20, CERCLA Operable Unit 1, Eielson Air Force Base, Alaska



TECHNOLOGY APPLICATION

In situ bioremediation (bioventing) of a JP-4 fuel spill in a subarctic environment.

SITE CHARACTERISTICS

Site History/Release Characteristics

- Eielson AFB is located 26 miles southeast of Fairbanks, Alaska and approximately 100 miles south of the Arctic Circle.
- Eielson AFB was constructed in 1944 and encompasses approximately 19,790 acres; 3,651 acres improved or partially improved; 16,139 acres undeveloped land encompassing forests, wetlands, lakes, and ponds.
- Eielson's primary mission since the early 1960s has been to provide tactical air support in direct support of Army ground elements assigned to Alaska.
- Past practices have caused groundwater and soil contamination.
- Floating petroleum products were encountered in 1972 in a 6-m test hole at the ST20 E-7 aircraft refueling pump house.
- Field investigations conducted in 1989 around the pump house identified an area of petroleum, oils, and lubricants (POL) contamination with floating product.
- The source area was determined to be the ST20 E-7 Complex, one of three active refueling complexes located at the south end of the runway.
- The complex consists of the asphalt pad centered along the taxiway with adjacent areas of gravel and grass, served by a fuel pump house (Building 1315), three 190,000-L defueling USTs, and several fueling and defueling transfer pipes.
- The initial date of operation is unknown.
- The actual source of contaminants is JP-4 fuel spills in the refueling area and leaks of JP-4 fuel from delivery lines for buried storage tanks. Fueling operations remain vital to the ongoing missions of the Base and will continue to serve as a part of future Base operations.
- Eielson AFB was added on the National Priorities List (NPL) in November 1989.
- The fuel-saturated area was assigned to CERCLA Operable Unit 1.

Contaminants of Concern

Total Petroleum Hydrocarbons (TPH)
Benzene
Toluene
Ethylbenzene
Xylene

Contaminant Properties

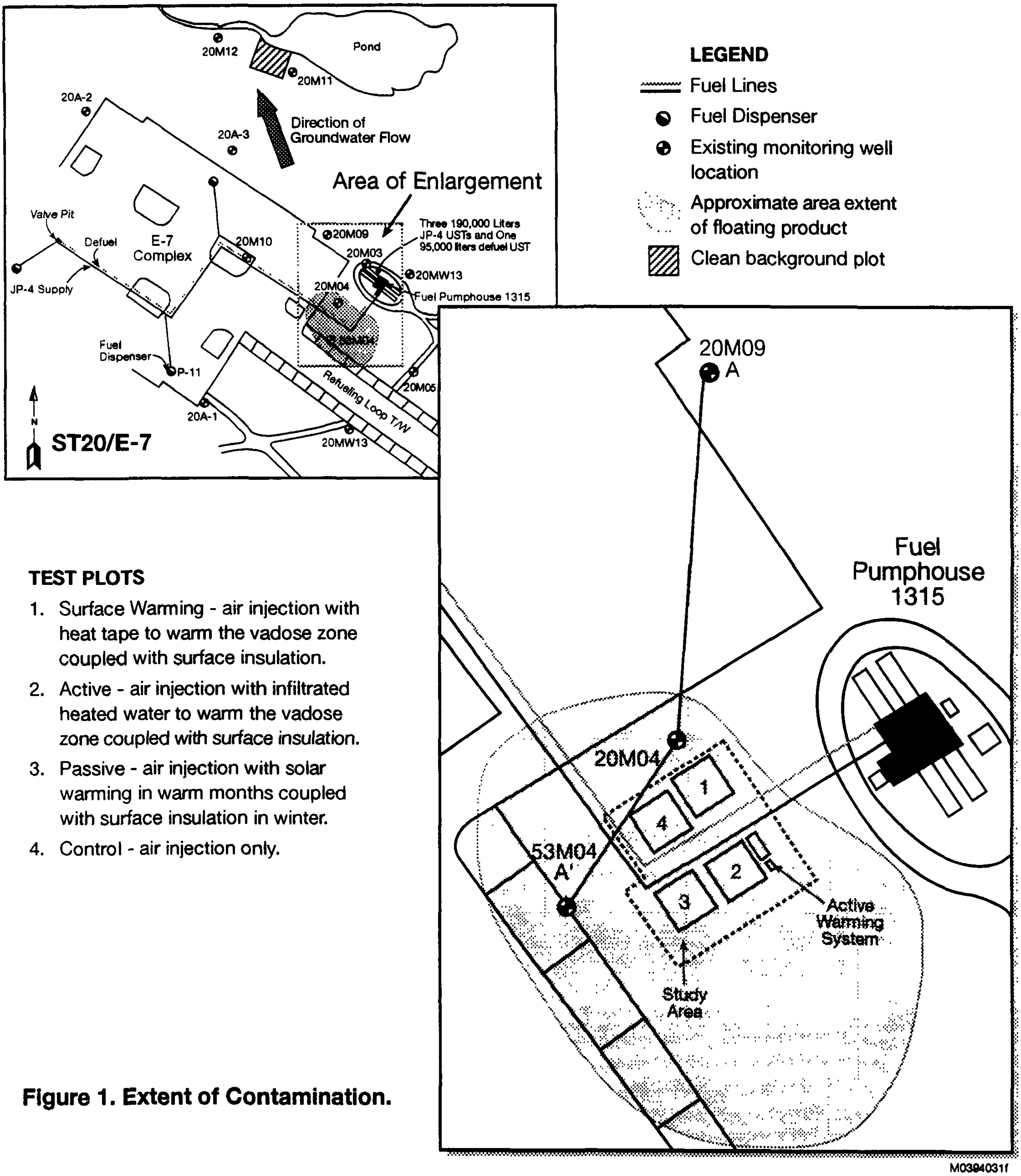
Properties of contaminants focused upon during remediation are provided below.

Property	Units	Benzene	Ethylbenzene	Toluene	Xylenes*
Empirical Formula		C_6H_6	C_8H_{10}	C_7H_8	C_8H_{10}
Density @ 20°C	g/cm³	0.88	0.87	0.87	0.87 (avg)
Melting Point	°C	5.5	-95	-95	-47.9 to 13.3
Vapor Pressure (20°C)	mm Hg	50	8.5	26	7.7
Henry's Law Constant (atm)(m³)/mol		5.59 x 10-3	6.43 x 10-3	6.37 x 10-3	7.04 x 10-3
Water Solubility	mg/l	1,750	152	535	198
Octanol-Water Partition Coefficient	Kow	132	1410	537	1830
Organic Carbon Partition	ml/g	83	1,100	300	240
Ionization Potential	ev	9.24	8.76	8.5	8.56
Molecular Weight		78.12	106.18	92.15	106.18

*All 3 isomers (M,O,&P)

Nature & Extent of Contamination

- Three static recovery wells were installed in the ST20 E-7 pump house test hole area and operated until February 1988, recovering 3,350 L of JP-4 fuel.
- Ten monitoring wells and numerous product probes were installed as part of the 1989 field investigation.
- Product measurements in 1993 indicated that the area extent of the measurable product has decreased, but product thickness has increased slightly from 1989 at well 20M04.
- Smearing of the floating product caused by seasonal changes in the water table is expected to have occurred.
- The downgradient extent of benzene concentrations in groundwater appears to be naturally degrading.
- The average contamination level is 1,500 mg total hydrocarbon per kg soil.
- The majority of the jet fuel is concentrated in areas below 5.25 feet.
- Figure 1 shows the approximate area of contamination.



TEST PLOTS

1. Surface Warming - air injection with heat tape to warm the vadose zone coupled with surface insulation.
2. Active - air injection with infiltrated heated water to warm the vadose zone coupled with surface insulation.
3. Passive - air injection with solar warming in warm months coupled with surface insulation in winter.
4. Control - air injection only.

Figure 1. Extent of Contamination.

Contaminant Locations and Geologic Profiles

Topography is generally flat and somewhat featureless with elevations ranging from 550 to 525 feet above mean sea level, sloping downward to the north-northwest.

Soil conditions at E-7 generally consist of interbedded layers of loose to medium dense gravel and sands with varying amounts of silt to approximately 2 meters below ground surface (bgs).

Sandy gravel is generally encountered at a depth of between 2.5 and 3 m. The upper 2.5 and 3 m consists of a variety of lithologies including silty gravel, sandy gravel, gravelly sand, sand, and silty sand. These units generally average 1-m thick. Silty sands and gravels are underlain by medium dense to dense sandy gravel more than 200 meters deep. Permafrost was not encountered during subsurface investigations.

The water table elevation at the site can fluctuate seasonably as much as 0.5 meters. Groundwater was encountered at depths between 1.7 and 2.6 meters bgs. Groundwater flow is generally to the north northwest. There is potential for interaction with surface water in the downgradient Refueling Loop ponds.

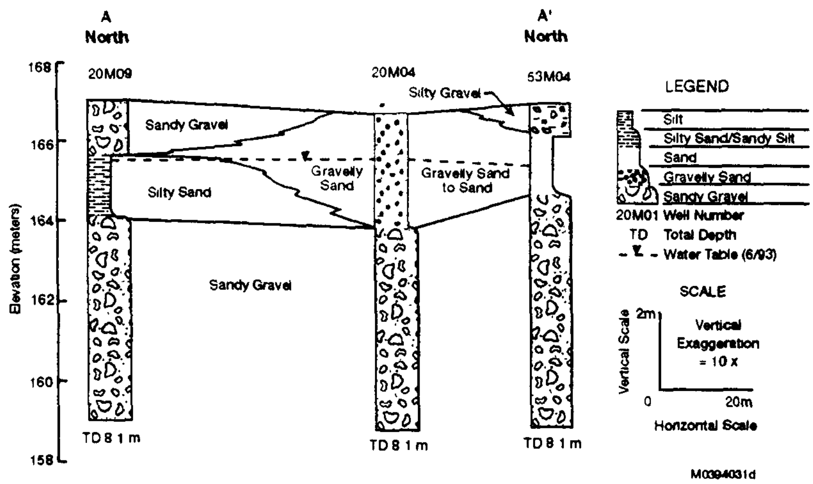


Figure 2. Cross Section A-A' for ST20 E-7 Complex

Nearby surface water bodies are used for local fishing and as possible sources of drinking water for moose. Three main base water supply wells are also located directly down gradient from ST20-E7. Residences start at approximately 1 to 1.2 miles from the ST20. The taxiway loop within ST20 is an airstrip which is in constant use. Hangars and alert hangars surround the site.

Site Conditions

The climate in the Eielson area is characterized as subarctic. Summer high temperatures are typically in the low to mid-eighties. Winter low temperatures are typically well below zero with moderate snowfall. Annual precipitation is 14 inches, annual lake evaporation is 10 inches, and net precipitation is 4 inches. The annual average wind speed is 5 mi/hr.

Key Soil or Key Aquifer Characteristics

Saturated Zone Data	Value
Thickness of Contamination	6.1 m
Aquifer Thickness	91.4 m
Pore-Water Velocity	10.0 cm/d
Hydraulic Conductivity	4 ft/d to 1000 ft/d
Effective Porosity	30.0%
Total Porosity	43.7%
Bulk Density	1.60 g/cm3

Aquifer Test Data at well 54M01 (ST20)	Value
Hydraulic Conductivity	1,480 ft/day
Horizontal Gradient	0.001
Storage Coefficient	0.07
Aquifer Thickness	20 ft
Effective Porosity	0.30

The average soil temperature during summer months is 40 °F. The silt content of the soil is 10%.

TREATMENT SYSTEM

A bioventing system has been operating at ST20 E-7 since July 1991 to investigate the feasibility of executing enhanced *in situ* bioremediation (bioventing) of soil contaminated with JP-4 fuel in a subarctic environment. Bioventing involves the aerating of subsurface soils to maximize biodegradation of biodegradable compounds while minimizing volatilization. Forced air *in situ* is used as a source of oxygen to promote microbial growth and the degradation process. Bioventing in conjunction with methods of soil warming at the source area have enhanced the biodegradation rate of JP-4 jet fuel in the soil.

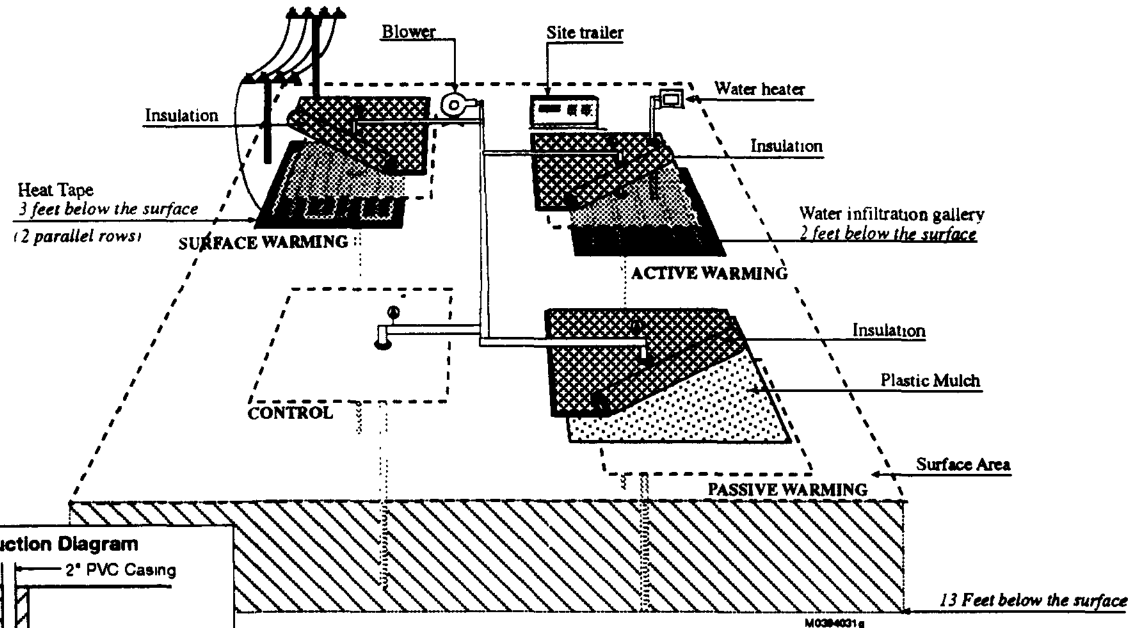
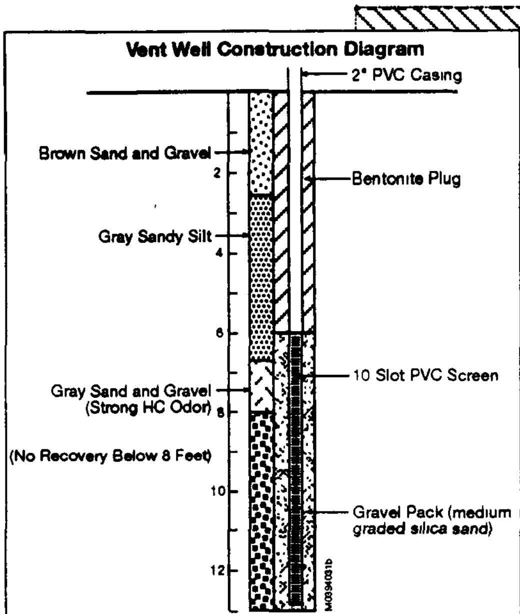


Figure 3



2-inch diameter PVC bioventing well installed.

Figure 1 in conjunction with Figure 3 show the bioventing system.

The original system was composed of several groups of vadose wells on a 30' grid connected to centrifugal blowers by insulated above-ground piping.

In 1992, the air injection system was modified replacing the grid system of air injection wells with one deeper well in the center of each of the test plots. Additionally, a fourth test plot was added that uses a buried heat tape to heat vadose zone soils.

PERFORMANCE

Performance Objectives

- To determine the effectiveness of the bioventing process in a sub-arctic environment and to evaluate potential enhancement of the process through soil warming.
- To prevent further degradation of the groundwater quality by significantly reducing the amount of petroleum product floating on the groundwater.

Treatment Plan

- It is estimated that 99% of the volatile petroleum hydrocarbons can be degraded through bioventing.
- All groundwater with a concentration of benzene in excess of 5 µg/l is targeted for cleanup. The remediation goal is to reduce the benzene concentration to below the drinking water standard of 5 µg/l.
- Bioventing at ST20 E-7 is being conducted as a three-year study which began in July 1991.
- To determine the effectiveness of bioventing in conjunction with soil-warming methods in a subarctic environment, the source area is divided into four 50-foot-square experimental plots.
- The plots are set up to test the effectiveness of three different types of soil warming, and are compared to the fourth control plot (Figure 1) which is maintained under ambient soil temperature conditions.
- One plot utilizes Passive Warming in which solar warming in late spring, summer, and early fall is enhanced by plastic sheeting placed over the ground surface of the plot. Insulation is used to cover the plot to help retain heat during late fall and the dark winter months.
- A second plot utilizes Active Warming in the vadose zone by infiltrating heated groundwater through soaker hoses buried 2 feet below ground surface. Water at 35°C is added an approximate rate of 1 gallon per minute through five parallel hoses spaced 10 feet apart. This plot is also covered by insulation year round.
- The third plot is a Surface Warming test plot using heat tape to add direct heat to the vadose zone soils. The heat tape is buried in parallel lines 5 feet apart, 3 feet below the surface, and delivers heat at a rate of 6 W/ft.
- The fourth plot is the contaminated Control plot which is biovented with no artificial method of heating. Air at ambient temperatures is simply injected into the contaminated soil.
- A Background plot of uncontaminated soil located away from the study area is also used for comparison.
- Air injection wells are installed in the center of each plot. The wells are screened from 6.5 ft to 13 ft to allow for deeper air injection. The air injection system was reconfigured in 1992 to inject air in the deep bioventing wells only at an average flow rate of 5 cubic feet per minute. Prior to 1992, a 30 foot grid system of shallower air injection wells operating at 2.5 cfm was used.
- Major operation and maintenance at ST20 include weekly sampling of soil gas concentrations, regular monitoring of soil temperature, and replacing the insulation material on the Active and Passive Warming plots as needed.
- Treatment of extracted soil gas is not anticipated.

The following assumptions were used:

- VOCs are released into the atmosphere at low rates during bioventing.
- No off-gas treatment or odor control was considered because flow rates are low.
- An air flow exchange rate of 0.6 pore volumes per day is sufficient to promote microbial activity.
- The effective porosity is 0.30.

Performance Measures

Each experimental plot has multi-level soil gas monitoring wells and multi-level soil temperature probes. Oxygen, carbon dioxide, and total petroleum hydrocarbons in the soil are measured regularly in order to estimate bacterial growth. Approximately once a month, the air injection system is turned off, and the oxygen levels are measured to see how quickly the microorganisms in the soil use the oxygen. Changes in soil gas concentrations of oxygen and carbon dioxide are monitored and compared with the Background plot to determine a relative biodegradation rate.

Preliminary conclusions show that bioventing in conjunction with soil warming is stimulating *in situ* biodegradation year round in this subarctic environment. Active warming maintains soil temperatures above ambient temperatures and thus increases biodegradation rates. The externally heated experimental plots are maintaining more higher, summer-like temperatures than the control plot, despite ambient air temperatures as low as -20°C.

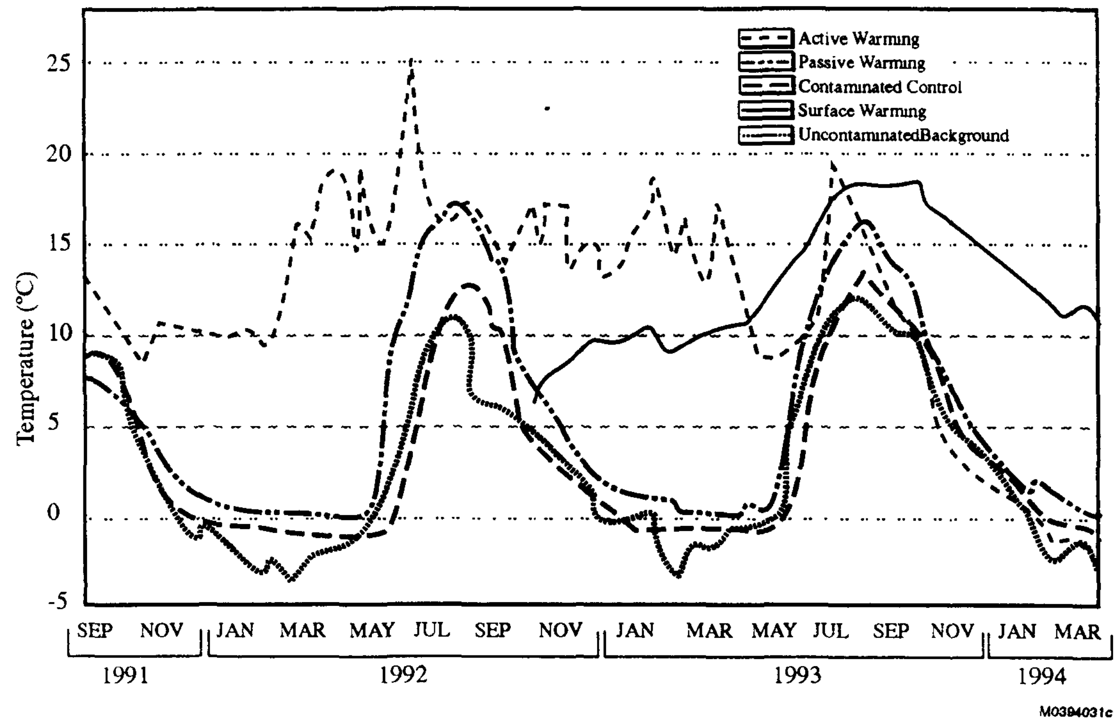


Figure 4. Soil temperature in the four test plots and the background area.

In the sixteen-month period from August 1991 to November 1992, the average respiration rates in the three original test plots are listed in the following table. The biodegradation rate in the Active Warming test plot is over twice the rate measured in the Control test plot:

Biodegradation
August 1991 to November 1992

Test Plot	Average Respiration Rates [mg/kg/day]	Hydrocarbon Removal [mg/kg]
Active	4.6	2,100
Passive	1.3	600
Control	1.6	750

Figure 5 summarizes the average biogradation from October 1991 to January 1993. Here the average biodegradation rates in the Active, and Surface Warming test plots are significantly higher than the rate measured in the Control test plot:

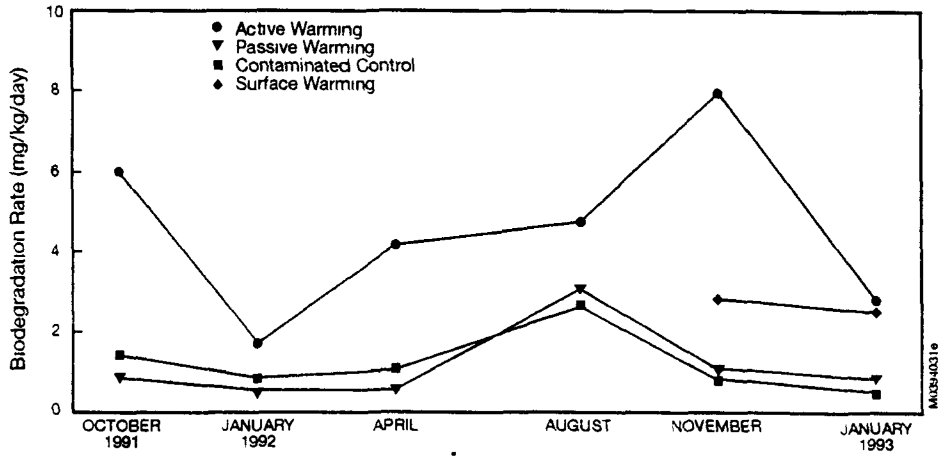


Figure 5

- A preliminary comparison of soil gas measurements taken from the Passive Warming test plot at the beginning of the bioventing demonstration and six months later shows a 60% to 97% decrease in total hydrocarbon vapor concentrations.
- Contaminant concentrations in soil and groundwater have been analyzed. The draft results indicate that the concentrations of benzene in groundwater samples collected from wells at ST20 (E-7) in 1993 were generally lower (maximum 200 µg/L) than those observed in samples collected at the time of the last sampling round in 1989 (maximum 12,000 µg/L). After the bioventing treatability study is completed during the 1994 field season, Eielson AFB may continue remediation at the site using bioventing.
- Surface emissions sampling has shown that benzene emissions are on the order of 0.00035 lbs/area/day, well below the Alaska State Department of Environmental Conservation limit of 4 lbs/area/day. Total TPH emissions were measured at 8.6 lbs/area/day versus 135 lbs/area/day of hydrocarbon removed through biodegradation.
- Soil vapor extraction testing has shown that removal of hydrocarbons due to biodegradation is an order of magnitude greater than hydrocarbon removal due to volatilization.

COST

The three-year bioventing system at ST20 E-7 is being conducted as a joint Air Force/EPA study. Battelle is the prime contractor for the Air Force and EPA component of the joint study.

Since the Eielson AFB Bioventing remediation is currently being conducted as study project, the system capital and operating do not accurately reflect the cost of remediating the ST20 E-7 site through bioremediation. An estimate of the costs involved if bioventing is chosen as the alterative for remediation of Eielson AFB source areas has been prepared by Battelle Pacific Northwest Labs and is summarized below. It should be noted that these costs are for multiple sites under arctic conditions. A more general cost for bioventing on a per cubic yard basis is found in *Bioventing Performance and Cost Summary*.

Capital Cost

Component Description	Category Subtotal
Floating Fuel	
Passive collection trenches installation	$14,500
Product collection pipes/sumps/pumps/storage	20,500
Soil Remediation - Bioventing	
Injection wells (30-35)	52,500
Above ground manifold system	140,000
Injection blowers	4,500
Trailer	6,000
Installation/Electrical/I&C	98,865
Start-up/Shakedown	10,000
Composting site development	16,180
Compost excavated soils	1,400
Groundwater Remediation	$3,000
Subtotal	$367,445
Mobilization & General Requirements @ 15%	55,167
Subtotal	$422,562
Contingencies	
Bid Contingency @ 10%	42,256
Scope Contingency @ 20%	84,512
Subtotal	$549,330
Other Costs	
Administrative @ 5%	27,467
Services During Construction @ 10%	54,933
Legal @ 5%	27,467
Implementation Cost Total	$659,197
Engineering Design @ 15%	98,880
	758,077

Annual Operations & Maintenance Cost

Component Description	Quantity	Unit price	Component Cost	Category Subtotal
Floating Fuel (5 Years Total Duration)				$21,000
Operating labor - 4 hours per week	208 hr	40	8,300	
Electric power	1 ls	5,000	5,000	
Trench maintenance	1 ls	500	500	
Monthly monitoring	96 hr	50	4,800	
Data management/Reporting	48 hr	50	2,400	
Soil Remediation - Bioventing (10 Years Total Duration)				$104,160
Fence and sign maintenance	48 hr	40	1,920	
Operating labor - 8 hours per week	416 hr	40	16,640	
Electric power	1 ls	20,000	20,000	
Monthly monitoring	240 ls	50	12,000	
Data Management/Reporting	192 hr	50	9,600	
Sample analysis	20 ea	1,200	24,000	
Maintenance	1 ls	1,000	1,000	
Groundwater Monitoring (30 Years Total Duration)				$52,000
Semi-annual sampling for VOCs	40 hr	50	2,000	
Data Management/Reporting	20 hr	50	1,000	
Sample Analysis	40 ea	1,200	48,000	
Well Maintenance	1 ls	1,000	1,000	
TOTAL				$177,160

REGULATORY/INSTITUTIONAL ISSUES

- Eielson Air Force Base is implementing remedial design and remedial action (RD/RA) activities at the Refueling Loop E-7 complex, designated Source Area ST20 (E-7), in accordance with the Federal Facilities Agreement between the United States Air Force, the Environmental Protection Agency (EPA), and the Alaska Department of Environmental Conservation (ADEC).
- The system is being operated on a test portion of the site by Battelle Columbus [sponsored through the United States Air Force Armstrong Laboratory, the United States Air Force Center for Environmental Excellence (AFCEE), and EPA].
- The Air Force has been designated as the lead government agency in cleanup efforts at Eielson AFB, Alaska. As the lead agency, the Air Force must ensure public involvement in all site-related decisions at Eielson AFB.
- No permitting will be required for purge water from the monitoring wells. Eielson AFB will provide for any required water treatment during well purging.
- Eielson AFB will be responsible for analysis and disposal of any soil or groundwater wastes generated.
- At the completion of the project all equipment will be left in place and will be turned over to the Air Force for continued operation.
- Administrative permits are not required for any treatment process carried out on the Base.
- Bioventing is expected to achieve the Alaska DEC ARAR for soil of 200 ppm TPH within 10 years.
- Recovered fuel is not a hazardous waste.
- Bioventing meets air discharge limits specified by the State.
- Institutional controls such as access restrictions, use of personal protective equipment, and continued use of the Base water treatment plant must be considered to prevent exposure to contaminated media during and after remedial activities.
- The ST20 refueling complexes contain active underground fuel tanks, piping, and pump houses. Special flight-line security passes are required for access, and additional security restrictions are imposed during Base exercises.
- The aquifer is used as the only source of potable drinking water source for the nearby community of Moose Creek.

SCHEDULE

Figure 6 shows the schedule of activities.

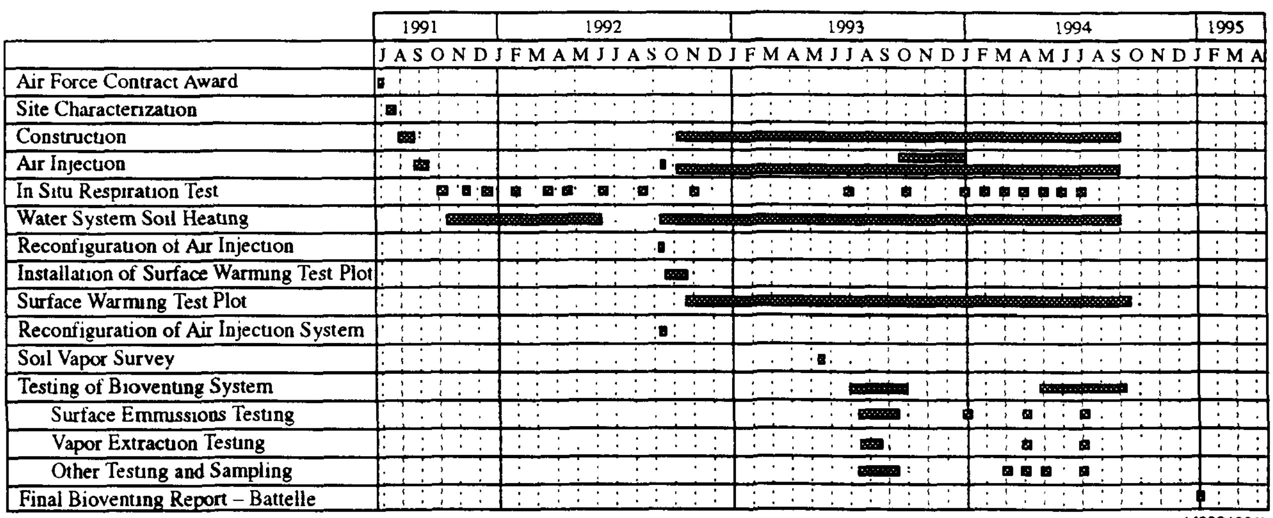


Figure 6. Interim Remediation Schedule.

LESSONS LEARNED

Implementation Considerations

- The ST20 refueling complexes contain active underground fuel tanks, piping, and pump houses. Special flight-line security passes are required for access, and additional security restrictions are imposed during Base exercises.
- The short construction season and arctic conditions affect implementation, operation, and maintenance.
- Base snow removal plowing services for site access roads must be coordinated.
- A bioventing system may be configured in several different ways to enhance biodegradation. The optimal configuration of any given site will depend on site-specific conditions and remedial objectives.
- The groundwater has naturally high concentrations of metals, including iron, arsenic, and manganese. Because the concentration of iron in the water is high, the introduction of oxygen or air into the groundwater could cause precipitation and fouling of equipment, wells, or the aquifer itself.

Technology Limitations

- Bioventing is an innovative technology, and data on effectiveness and time to achieve cleanup goals are limited. The reliability and effectiveness of bioventing depend on oxygen, nutrients, moisture, and microbial populations present in the soil.
- Injection wells may be impractical from a maintenance standpoint at sources areas with a naturally high content of iron in the groundwater.
- High soil moisture content especially in the Active Warming plots interferes with soil gas monitoring and reduces the number of soil gas monitoring points that can be sampled. In general, the deeper monitoring points where the most contamination is present are the most difficult to sample. The use of heat tape may prove to be the preferred means of soil warming since the problem of high soil moisture content is avoided.
- Many types of batteries, as well as the electronics in many field instruments can be adversely affected by the cold. Manufacturers literatures must be consulted for operating ranges. Additional time must also be allotted in the morning to check out and warm-up field equipment.

Future Technology Selection Considerations/Alternatives

SVE/Bioventing/Sparging:

- SVE is a reliable, proven technology for VOC remediation.
- SVE and bioventing are expected to remove a high percentage of the volatile compounds and perhaps up to 50 percent of the residual contamination.
- Bioventing may release VOCs into the air at a very low rate.
- Air sparging releases volatile compounds to the SVE system. Catalytic oxidation of SVE off gas thermally destroys organic contaminants.
- High-iron content in groundwater may limit feasibility of sparging using air.

Removal:

- The removal alternative provides the greatest protection to future groundwater users in the shortest time frame through source removal (active skimming and excavation) and groundwater extraction.
- Active skimming reduces the source of groundwater contamination by removing up to 50% of the floating fuel. However, residual fuel contaminants may continue to leach to groundwater.
- Groundwater extraction is proven for removing contaminant mass, but not for aquifer restoration.
- Excavating "hot spots" eliminates current and future exposure from concentrated areas of contamination, but lower levels of contamination in soil may be widespread.
- VOCs will be released to the air during excavation, composting, and air stripping.
- In addition, underground fuel lines, utilities, and fuel storage tanks may pose a hazard during excavation.

SOURCES

Major Sources For Each Section

Site Characteristics	1, 2, 3, 4, 5, 7, 8, 10
Treatment System	1, 5, 6, 9
Performance	1, 3, 5, 6, 9, 12, 15
Cost	1, 13, 14, 15, 16, 18
Regulatory/Institutional Issues	1, 5, 6, 8, 10, 14
Schedule	1, 6, 15
Lessons Learned	1, 5, 11

REFERENCES

Administrative Record Code [Information Repository, Eielson Air Force Base, AK]	Document Description
1. 003473	U.S. Air Force. 1992. Environics TOC Task 3 Bioventing Feasibility Study: Eielson Air Force Base. Annual Report, December 1992. In preparation for the U.S. Air Force by BATTELLE Columbus Division, Columbus, Ohio.
2. 003286	U.S. Air Force. 1992. OUIB Record of Decision, Eielson Air Force Base, Alaska. September 1992.
3. 003742	U.S. Air Force. 1993. Remedial Investigation/Feasibility Study. Operable Unit 1 Management Plan, Eielson Air Force Base, Alaska. Draft Final, May 1993. U.S. Air Force Environmental Restoration Program.
4. 003838	U.S. Air Force. 1993. Operable Unit 1 Remedial Investigation Report, Volume 1, Text and Appendixes, Eielson Air Force Base, Alaska. Draft, August 1993. U.S. Air Force Environmental Restoration Program.
5. 003853	U.S. Air Force. 1993. Operable Unit 1 Feasibility Study, Volume 3: Text and Appendixes, Eielson Air Force Base, Alaska. Draft, November 1993. U.S. Air Force Environmental Restoration Program.
6. 003830	U.S. Air Force. 1993. Interim Remedial Action. Remedial Design: OUIB Source Area ST-20 (E-7). Draft, September 1993. Prepared for Eielson Air Force Base through Armstrong Laboratory, Brooks Air Force Base, San Antonio, Texas.

7. 003926 — U.S. Air Force. 1993. Management Action Plan, Eielson Air Force Base, Alaska. Revision, 17 December 1993. U.S. Air Force Environmental Restoration Program.

8. 002694 — 343d Fighter Wing. Eielson Air Force Base Community Relations Plan for Environmental Restoration. October 1991. Eielson Air Force Base Installation Restoration Program.

9. 003375 — 343d Fighter Wing. Fact Sheet: Bioventing. December 1992. Eielson Air Force Base Installation Restoration Program.

10. On File in Information Repository — U.S. Air Force. Base-General Information for DPM FY-93 U.S. Air Force Scoring Exercise. DPM Information Packet based on Site 20 data. Completed on 5 January 1994 by 354 CES/CEVR, Eielson Air Force Base, Alaska. Submitted to Engineering Science, Fairfax, Virginia.

NOTE: A final report from Battelle summarizing the results and conclusions of the Site 20 bioventing research project will be prepared by December 1994.

Additional Sources of Information

11. Office Copy — Vogel, Catherine M. Soil Bioventing Under Arctic Conditions. The Military Engineer Magazine, August 1993.

12. Correspondence [Project File] — Kittel, Jeffrey A. Letter from Jeffrey Kittel of Battelle (Columbus, OH) in response to a request from Capt. Catherine Vogel of HQ AFCESA/RAVW (Tyndall AFB, FL), dated 31 December 1993. SUBJECT: Estimate to Complete the Bioventing Field Research Project at Site 20, Eielson AFB, AK.

13. Correspondence [Project File] — Battelle. Faxed submittal from Battelle (Columbus, OH) to Lafayette Turner of AFDTC/PKRA (Eglin AFB, FL), dated 5 March 1993. SUBJECT: Full-scale Bioventing Demonstration in Alaska, Environics Task Order Contract Task 3, Contract No. F08635-90-C-0064. Proposal for completion of the above referenced task (includes proposed funding).

14. Correspondence [Project File] — Vogel, Catherine M. Fax from Capt. Catherine Vogel at AL/EQ (Tyndall AFB, FL) to Dave Blevins of 354 CES/CEVR (Eielson AFB, AK), dated 8 March 1993. SUBJECT: FY 92 Bioventing Funding. Fax includes copies of the Battelle bills (monthly invoices) for 3 September 1992 through 25 February 1993.

15. Monthly Status Reports [Project File] — Battelle. Copies of Monthly Status Reports from Dr. Robert E. Hinchee of Battelle (Columbus, OH) to Capt. Catherine Volge of AL/EQW (Tyndall AFB, FL) for August 1992 through December 1993. SUBJECT: [Thirteenth through Twenty-Ninth] Monthly Status Report, Full-Scale Bioventing Demonstration in Alaska, Task 3, Contract F08635-90-C-0064.

16. Report — Bioventing Performance and Cost Summary, February 1994. Air Force Center for Environmental Excellence, Brooks AFB, Texas.

Key Personnel/ Points of Contact:

17. Capt. Catherine Vogel, USAF
Contract/Project Officer

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Tyndall AFB, FL 32403-5319

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    Eielson Air Force Base, Alaska 99702-2225

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21. Jennifer R. Kiger — 354 CES/CEVR
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    Technology Demonstration — Eielson Air Force Base, Alaska 99702-2225
    Point of Contact

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REVIEW

X [signature]
Capt. Chester Halcomb
354 CES/CEV
2258 Central Avenue, Suite 1
Eielson AFB, AK 99702

Slurry-Phase Bioremediation at the French Limited Superfund Site Crosby, Texas

Case Study Abstract

Slurry-Phase Bioremediation at the French Limited Superfund Site, Crosby, Texas

Site Name:
French Limited Superfund Site

Location:
Crosby, Texas

Vendors:
Jonathan Greene
ENSR
3000 Richmond Avenue
Houston, TX 77098
(713) 520-9900
Gary Storms
Praxair, Inc.
39 Old Ridgebury Road
Danbury, CT 06810
(203) 837-2174

SIC Code:
4953E (Waste management-refuse systems; sand and gravel pit disposal)

Waste Source:
Disposal pit

Purpose/Significance of Application:
A large full-scale application of slurry-phase bioremediation of a lagoon at a Superfund site. An innovative system was used to minimize air emissions during the remediation.

Contaminants:
Polynuclear Aromatic Hydrocarbons (PAHs) and Chlorinated Aliphatics;
- Primary constituents included benzene, vinyl chloride, and benzo(a)pyrene
- Site contaminants included volatile organics (up to 400 mg/kg); pentachlorophenol (up to 750 mg/kg); semivolatiles (up to 5,000 mg/kg); metals (up to 5,000 mg/kg); PCBs (up to 616 mg/kg) and arsenic

Technology:
Slurry-Phase Bioremediation
- Two treatment cells designed to hold 17 million gallons each
- Mixflo™ aeration system used to maintain dissolved oxygen concentration at 2.0 mg/L
- Tarry sludge dredged and treated separately from subsoil in lagoon

Period of Operation:
January 1992 to November 1993

Cleanup Type:
Full-scale cleanup

Cleanup Authority:
CERCLA
- ROD Date: 3/24/88
- PRP Lead

Point of Contact:
Judith Black
Remedial Project Manager
U.S. EPA Region 6
1445 Ross Avenue
Dallas, TX 75202
(214) 665-6739

Type/Quantity of Media Treated:
Soil and Sludge
- Approximately 300,000 tons
- Soils varied from fine grained silts to coarse sand
- Sludges - tar-like consisting of a mixture of petrochemical sludges, kiln dust, and tars (styrene and oils)

Slurry-Phase Bioremediation at the French Limited Superfund Site, Crosby, Texas (Continued)

Regulatory Requirements/Cleanup Goals:
- The ROD specified maximum allowable concentrations in the lagoon subsoils and sludges for 5 contaminants: benzo(a)pyrene (9 mg/kg), total PCBs (23 mg/kg), vinyl chloride (43 mg/kg), arsenic (7 mg/kg), and benzene (14 mg/kg)
- The ROD specified an action level for total VOCs of 11 ppm for 5 minutes at the site boundary at any time during treatment

Results:
- The specified cleanup criteria were met within 10 months treatment for Cell E and 11 months treatment for Cell F
- There were no exceedances of the established criteria for VOC air emissions

Cost Factors:
- Total costs were approximately $49,000,000 (including project management, pilot studies, technology development, EPA oversight, and backfill of the lagoon)
- $26,900,000 of total costs were for activities directly attributed to treatment (including solids, liquid, and vapor/gas preparation and handling, pads/foundations/spill control, mobilization/setup, startup/testing/permits, training, and operation)
- $16,500,000 were for before-treatment activities (including mobilization and preparatory work, monitoring sampling, testing, and analysis, site work, surface water, groundwater, and air pollution/gas collection and control, solids and liquids/sediments/sludges collection and containment, and drums/tanks/structures/miscellaneous demolition and removal)
- $5,600,000 were for after-treatment activities (including decontamination and decommissioning, commercial and non-commercial disposal, site restoration, non-treatment unit demobilization, topsoil, and revegetation)

Description:
The French Ltd. Superfund site in Crosby, Texas, is a former industrial waste disposal facility where an estimated 70 million gallons of petrochemical wastes were disposed in an unlined lagoon at the site between 1966 and 1971. The primary contaminants at the site included benzo(a)pyrene, vinyl chloride, and benzene, as well as arsenic and PCBs.

In 1983, the Potentially Responsible Parties (PRPs) formed the French Limited Task Group (FLTG) to lead the remediation at the site. The ROD, signed in March 1988, specified bioremediation of the lagoon. In addition, the ROD specified soil cleanup goals for five target contaminants (benzo(a)pyrene, total PCBs, vinyl chloride, arsenic, and benzene). Slurry-phase bioremediation of the lagoon was performed from January 1992 through November 1993. An innovative system (the MixFlo system) was used for aeration in this application that minimized air emissions while supplying oxygen to the biomass. This system used pure oxygen and a series of eductors to oxygenate the mixed liquor while minimizing air emissions. During this time, approximately 300,000 tons of contaminated sludge and soil in the lagoon were treated to levels below those specified in the ROD. In addition, air emission limits specified in the ROD were not exceeded during treatment. Total costs for the system were approximately $49,000,000, including approximately $26,000,000 for activities directly attributed to treatment.

This application is notable as being the first application of slurry-phase bioremediation at a Superfund site, and included approximately $12,000,000 in technology development and pilot-scale testing work. According to FLTG, the costs for future applications of slurry-phase bioremediation depend on site-specific chemical and physical conditions with oxygen and nutrient supply being key factors affecting the cost of bioremediation systems.

COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for a slurry-phase bioremediation application at the French Limited Superfund Site (French Ltd.) in Crosby, Texas. This project is notable for being a large, full-scale application of slurry-phase bioremediation at a Superfund site. In addition, an innovative system (the MixFlo system) was used for aeration that minimized air emissions while supplying adequate oxygen to the biomass.

The French Ltd. site is a former permitted industrial waste disposal facility, where an estimated 70 million gallons of wastes from area petrochemical companies were disposed of on site between 1966 and 1971, primarily in an unlined lagoon. Contaminants of concern included polynuclear aromatic hydrocarbons, chlorinated organics, and metals.

In 1983, the Potentially Responsible Parties (PRPs) formed the French Limited Task Group (FLTG) to lead the remediation at the site. A Record of Decision (ROD) was signed on March 24, 1988. The ROD specified bioremediation for remediation of the lagoon. A slurry-phase bioremediation process was operated from January 1992 through November 1993 to remediate approximately 300,000 tons of tar-like sludge and subsoil from the lagoon. The slurry-phase bioremediation process achieved the specified soil cleanup goals for the five target contaminants (benzo(a)pyrene, total PCBs, vinyl chloride, arsenic, and benzene) within 11 months of treatment.

Costs for the slurry-phase bioremediation system including technology development, project management, EPA oversight, and backfill of the lagoon were approximately $49,000,000. Approximately $26,900,000 in costs were for activities directly associated with treatment, which corresponds to $90/ton for treatment of 300,000 tons of soil and sludge.

SITE INFORMATION

Identifying Information

Site Information: French Limited Superfund Site
Crosby, Texas
CERCLIS # TXD980514814
ROD Date: 24 March 1988

Treatment Application

Type of Action: Remedial
Treatability Study Associated With Application? Yes (See Appendix A)
EPA SITE Program Test Associated With Application? No
Period of Operation: January 1992-November 1993
Quantity of Material Treated During Application: 300,000 tons of soil and sludge; estimated as 70,000 tons of tar-like sludge and 230,000 tons of subsoil, determined by borings of the lagoon bottom.

Background

Historical Activity that Generated Contamination at the Site: Industrial Waste Disposal

Corresponding SIC Code: 4953E (Waste management-refuse systems; sand and gravel pit disposal)

Waste Management Practice that Contributed to Contamination: Disposal Pit

Site History: The French Limited Superfund Site (French Ltd.), a former industrial waste storage and disposal facility, is a 22.5-acre site located in Crosby, Texas, as shown in Figure 1. Between 1966 and 1971, approxi-

SITE INFORMATION (CONT.)

Background (cont.)

mately 70 million gallons of industrial wastes from area petrochemical companies were disposed of at the French Ltd. site. These wastes included tank bottoms, pickling acids, and off-specification product from refineries and petrochemical plants. Most of this waste was deposited in an unlined, 7.3-acre lagoon. Wastes were also processed in tanks and burned.

The lagoon was an abandoned sand pit which had filled with water to depths of 20 to 25 feet. The primary contaminants found in the lagoon were polynuclear aromatic hydrocarbons, halogenated semivolatiles, halogenated volatiles, nonhalogenated volatiles, metals, and nonmetallic elements. The lagoon wastes were concentrated in a layer of tar-like sludge approximately 4 feet thick and a 5-6 foot layer of subsoil. [1, 35, 37, 39]

The site is located within the 100-year floodplain of the San Jacinto River and is susceptible to periodic flooding. In May of 1979, a flood occurred and breached the earthen dike which surrounded the lagoon. As a result, contaminated sludges were washed out of the lagoon and into an adjacent slough. In 1982, EPA repaired the dike and pumped the contaminated sludge from the slough back into the lagoon. [1, 9]

EPA identified approximately 90 companies as Potentially Responsible Parties (PRPs), and, in 1983, the PRPs formed the French Limited Task Group (FLTG). In 1984, FLTG agreed to perform the cleanup. [1, 8, 9]

EPA conducted a Remedial Investigation (RI) at the site in 1983, and the FLTG conducted a field investigation and a second RI in 1986. Selection of a remedy for the lagoon was based on the results of the 1983 and 1986 investigations and a Feasibility Study (FS). EPA initially proposed incineration as the remedial technology for the tar-like sludge and affected subsoil at an estimated cost of $75 to $125 million. FLTG then investigated other more cost-effective alternatives. In 1987, FLTG conducted a pilot-scale bioremediation treatability study in a 0.6-acre section of the lagoon (see Appendix A). As a result of the study, a 1988 ROD replaced incineration with in-situ biodegradation for remediation of the site. [1, 8]

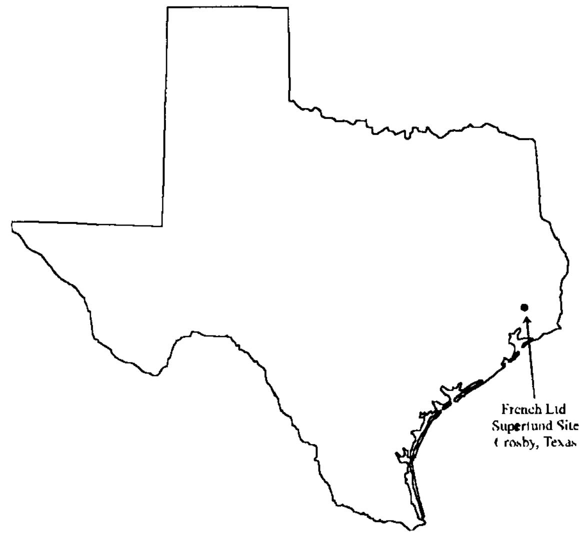

Figure 1. Site Location

Regulatory Context: The ROD specified risk-based quantitative cleanup goals for five types of contaminants on the bottom of the lagoon at the French Ltd. site, as described below under cleanup goals and standards. The ROD also provided specifications for groundwater recovery and treatment. [1]

Remedy Selection [1]: The following remedial action alternatives were considered for the French Ltd. site:

- On-site incineration of tar-like sludge and contaminated subsoil;
- On-site incineration of tar-like sludge and chemical fixation of contaminated subsoil in-place;
- Encapsulation of contaminants by slurry walls and a multilayered cap;
- No action; and
- Biological treatment of tar-like sludge and contaminated subsoil.

Biological treatment of sludges and contaminated subsoils was selected because it was believed to be capable of meeting the cleanup goals in a reasonable period of time and at a lower cost than incineration.

SITE INFORMATION (CONT.)

Background (cont.)

The ROD indicated that the probability of bioremediation failing was less than for other options. However, if bioremediation failed, the ROD discussed the use of incineration as a backup.

Site Logistics/Contacts

Site Management: PRP Lead

Oversight: EPA

Remedial Project Manager:
Ms. Judith Black
U.S. EPA Region 6
1445 Ross Avenue
Dallas, Texas 75202-2733
(214) 665-6739

PRP Project Coordinator:
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Treatment System Vendors:
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Mr. Gary Storms (Subcontractor)
Applications Manager
Waste Management
Praxair, Inc.
39 Old Ridgebury Road
Danbury, Connecticut 06810
(203) 837-2174

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix processed through the treatment system: Tar-like sludge and subsoil (in situ - within lagoon)

Contaminant Characterization [1]

Primary Contaminant Groups: Polynuclear aromatic hydrocarbons; halogenated semivolatiles; halogenated volatiles; nonhalogenated volatiles; and nonmetallic elements.

The soil and tar-like sludge in the lagoon contained a variety of organics, metals, and PCBs. The specific types and concentrations of constituents, as identified in the ROD, included:

- PCBs up to 616 mg/kg;
- Volatile organics up to 400 mg/kg for an individual contaminant;
- Pentachlorophenol up to 750 mg/kg;
- Semivolatiles up to 5,000 mg/kg for an individual contaminant; and
- Metals up to 5,000 mg/kg for an individual metal.

Concentrations of specific contaminants in the soil and sludge are presented in the Treatment Performance Data section of this report.

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Cost or Performance

Listed below in Table 1 are the major matrix characteristics affecting cost or performance for this technology, and the values measured for each.

The tar-like sludge was aromatic and oily, and consisted of a mixture of petrochemical sludges, kiln dust, and tars (primarily styrene and soils). It was a thick, viscous, oily, black layer about 4 feet thick that covered the bottom of the lagoon. The subsoils varied from fine grained silts to coarse sand. [38, 39]

Table 1. Matrix Classification [38,39]

Parameter	Value	Measurement Procedure
Soil Classification	See discussion above	--
Clay Content and/or Particle Size Distribution	See discussion above	--

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology Type

Slurry-Phase Bioremediation

Supplemental Treatment Technology Type

Pretreatment (solids) - mixing

Slurry-Phase Bioremediation System Description and Operation

The slurry-phase bioremediation system used at French Ltd. stimulated the indigenous microorganisms with aeration, pH control, and nutrients to biologically oxidize the organic waste materials. The tar-like sludge was sheared and introduced into the mixed liquor using open-faced centrifugal pumps mounted on articulated arms. The subsoil was sheared and introduced into the mixed liquor using conventional swinging ladder cutter head dredges. Controlled shearing was a key factor in controlling the growth of biomass. Biomass growth was also controlled by controlling the level of dissolved oxygen and pH. [9, 35]

The tar-like sludge and subsoils were treated separately. If the soils and sludge had been mixed together, the sludge would have coated the soil particles, and the mixture would have had a greater specific gravity and settled more rapidly, thus reducing treatment effectiveness. Treating the sludge separately kept the sludge from coating the soil particles and maximized the surface area available for treatment. [39]

System Description

As shown in Figure 2, the lagoon was divided into two treatment cells, Cell E and Cell F, of approximately equal volume. The two treatment cells were created by installing a sheet pile wall across the lagoon in a north-south direction so there would be equal treatment media volume in each of the two cells. This configuration allowed for the sequential remediation of the western cell (Cell E) and the eastern cell (Cell F). Additional benefits of the sequential remediation approach were to limit air emissions during the remediation; reduce the amount of capital equipment that had to be purchased; and allow for process improvements over the duration of the remediation. [9]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Slurry-Phase Bioremediation System Description and Operation (cont.)

The treatment cells were designed to hold a total mixed liquor volume of 34.0 million gallons (17.0 million gallons in each treatment cell), and to maintain a minimum dissolved oxygen (DO) concentration of 2.0 mg/L in the mixed liquor. Based on the results of the treatability study (see Appendix A), an oxygen uptake rate (OUR) of 0.30 mg/L/minute was chosen as the design basis for aeration supply. The oxygen requirements were determined by multiplying the OUR by the total mixed liquor volume. Oxygen requirements for each cell were determined to be approximately 2,500 pounds/hour. [9]

The main components of the bioremediation process, as shown in Figures 3 and 4, included a MixFlo aeration system, a liquid oxygen supply system, a chemical feed system, and dredging and mixing equipment. A description of the MixFlo Aeration System, sludge and subsoil mixing, chemical addition, and residuals management is presented below.

MixFlo Aeration System

According to the vendor, the FLTG chose a pure oxygen system rather than an air-based aeration system to lower air emissions during site remediation. Greater amounts of organic air emissions are released from air-based aeration systems because larger amounts of air are required to achieve a specific dissolved oxygen content. The MixFlo system has higher transfer efficiencies than air-based aeration systems (90% as opposed to 30%) and uses high purity oxygen (90% or greater). This combination of higher transfer efficiency and high purity oxygen reduces offgases and air emissions from the treatment process. [35]

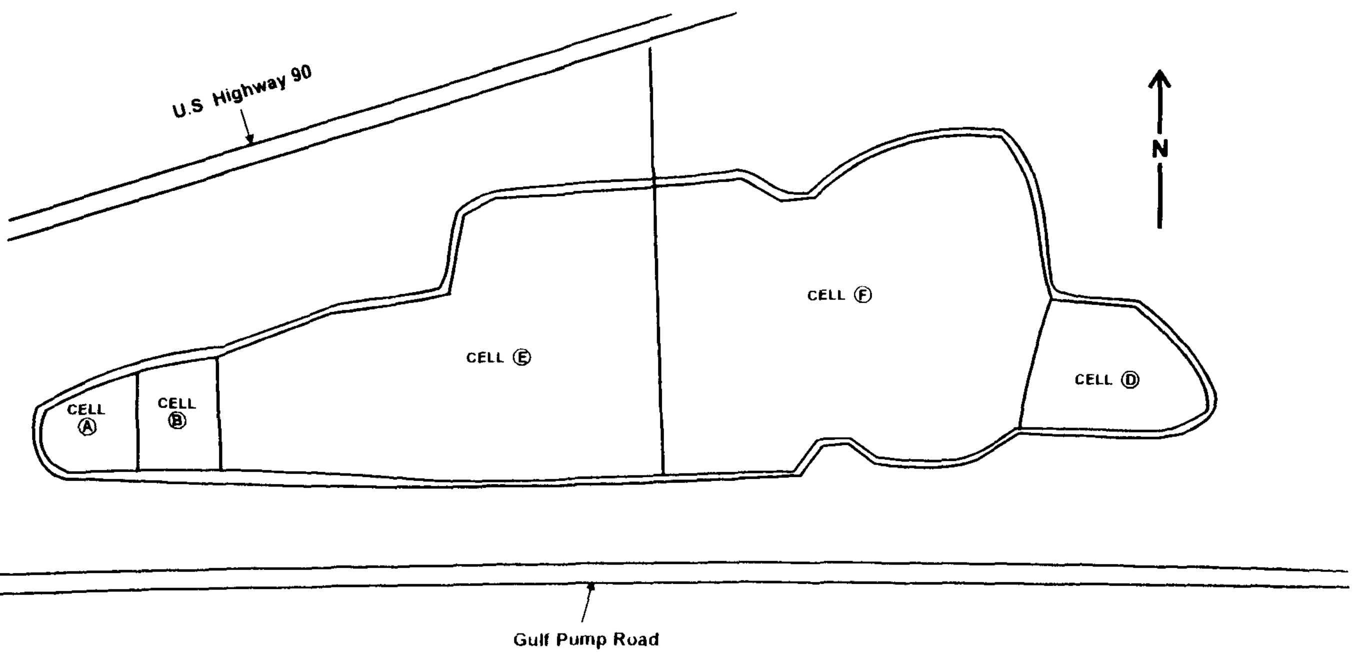

Figure 2. French Ltd. Lagoon and Bioremediation Treatment Cell Configuration [9]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Slurry-Phase Bioremediation System Description and Operation (cont.)

The MixFlo aeration system used at French Ltd. dissolves oxygen in a two-stage process, as shown in Figure 3. In the first stage, water is pumped from the treatment area and pressurized. Pure oxygen is then injected into the water. The resulting two-phase mixture passes through a pipeline contractor where approximately 60% of the injected oxygen dissolves. In the second stage, the oxygen/ water mixture is reinjected into the treatment area using a liquid/liquid eductor. The eductor dissipates the pumping energy in the oxygen/ water mixture by ingesting unoxygenated water from the treatment area, mixing it with oxygenated water, and then discharging the overall mixture back into the treatment area, dissolving 75% of the remaining oxygen. [9]

At French Ltd., oxygen was injected in eight pipeline contactors into the mixed liquor at enhanced pressure. The mixed liquor was pressurized by pumps located on two pontoons. The pipeline contactors each supplied three eductors. The circulation flow pattern in the treatment cell established by the eductors' discharge was supplemented by three raft-mounted self-powered circulation mixers. [9]

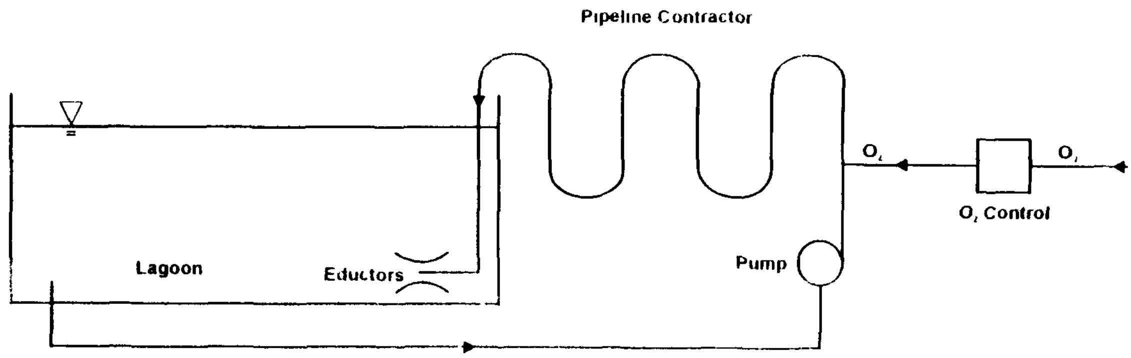

Figure 3 Schematic Diagram of Mixflow System (adapted from [41])

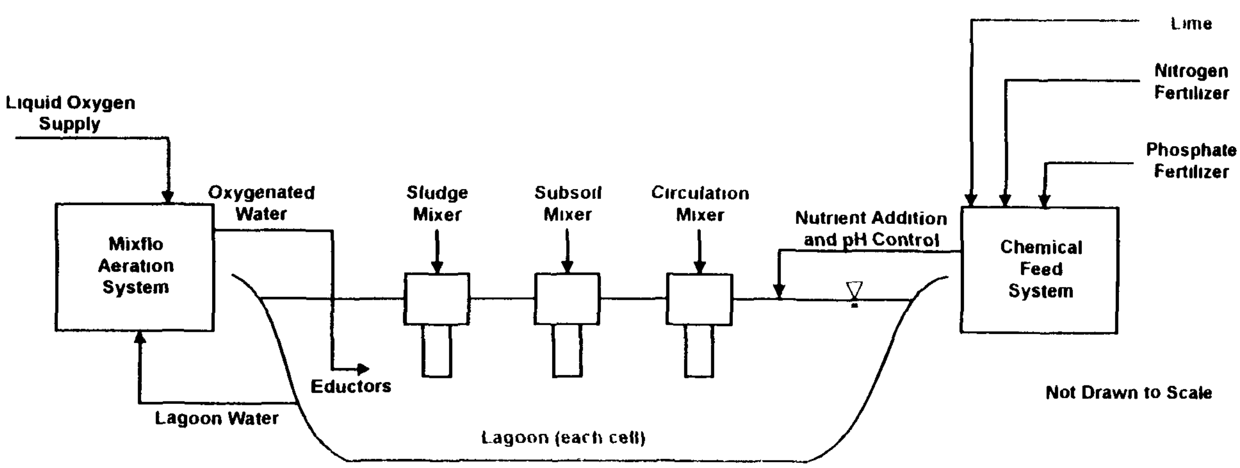

Figure 4. French Ltd. Lagoon Treatment Process Flow Diagram (adapted from [9])

TREATMENT SYSTEM DESCRIPTION (CONT.)

Slurry-Phase Bioremediation System Description and Operation (cont.)

Oxygen was distributed to the entire volume of mixed liquor in the treatment cell by creating a dual circulation pattern that moved mixed liquor past and through the MixFlo eductors to pick up oxygen, and circulated it around the lagoon where oxygen was consumed in the bioremediation process. [9]

The design of the MixFlo system was based on the following criteria [9]:

- Capacity = 60,000 gpm;
- Motor Power = 3,400 hp;
- Oxygen Transfer Efficiency $\geq$90%;
- Temperature = 40°C;
- Oxygen Requirement = 2,500 lbs/hr;
- Liquid Depth = 10 feet;
- Pump Efficiency = 75%; and
- Saturation Oxygen Concentration (C) = 0.9 x $C_{40°C}$ (tap water) = 27.5 ppm

Sludge and Soil Mixing

As described above, different equipment was used for dredging and mixing the tar-like sludges and subsoil. Four sludge mixers provided the shear mixing of sludges necessary to achieve biological treatment of those solid materials. The centrifugal pump selected for use on the sludge mixers had a capacity of 1,250 gallons per minute. [9] Four hydraulic subsoil mixers provided the shear mixing of lagoon bottom subsoils necessary to achieve biological treatment of the waste constituents adsorbed onto these solid materials. Maximum water depth was approximately 25 feet. [9]

Chemical Addition

Simple batch systems for chemical addition were used to control the pH and nutrient chemistry of the mixed liquor during treatment. A 35% solution of hydrated lime was diluted on site to 15% concentration by adding water. To offset nutrient losses, nitrogen was added as hydrated urea (46% nitrogen by weight) and phosphorus was added as liquid ammonium phosphate. The system was designed to add batches of up to 1,500 gallons of chemicals to the lagoon at several locations. [9]

Residuals Management

After verification that soil and sludge cleanup objectives had been achieved, reverse osmosis was used to treat the surface water in the lagoon. Approximately 40 million gallons of surface water from the lagoon were processed through the reverse osmosis system and discharged to the San Jacinto River. As the lagoon was dewatered, it was backfilled with clean soil. Residual solids were stabilized by mixing with pebble lime in the ratio of five parts solids to one part pebble lime. The site was then planted with grass and native vegetation and contoured to drain away from the lagoon. [34]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Operating Parameters Affecting Treatment Cost or Performance

Listed below in Table 2 are the major operating parameters affecting cost or performance for this technology and the values measured for each. System throughput and hydrocarbon degradation are described under system description and treatment performance data, respectively.

Table 2. Operating Parameters [10-33]

Parameter	Value	Measurement Procedure
Air Flow Rate	2,500 lbs/hr oxygen	---
Dredging Hours	358 to 1,669 hrs/month	---
Mixing Hours	1,164 to 2,052 hrs/month	---
Moisture Content	70% to 95%	Not Available
pH	6.6 to 8.5	Not Available
Residence Time	11 months (Cell F), 10 months (Cell E)	Not Available
Temperature	71.6 to 98.6° F	Not Available
Microbial Plate Count	10^5 to 10^7 CFU/ml	Not Available
Oxygen Uptake Rate	0.9 to 30 mg/L/hr	Not Available
Dissolved Oxygen Content	0.5 to 4.0 mg/L	Not Available
HMB Catalyst Activity	0.4 to 50 units	Not Available
Nutrient Nitrogen Content	0.05 mg/L	Not Available
Nutrient Phosphorus Content	0.05 to 10 mg/L	Not Available

Timeline

A timeline for this application is provided in Table 3.

Table 3. Timeline [1, 9]

Start Date	End Date	Activity
---	10/83	Site added to the National Priorities List
4/87	4/88	Biological treatment pilot study conducted on site in a 0.5-acre cell
---	3/88	ROD signed
---	3/90	Remedial Action Plan prepared
1/91	6/91	Remedial Design prepared
7/91	12/91	Cleanup facility construction completed
1/92	11/92	Bioremediation of Cell E
11/92	12/92	Transfer of bioremediation equipment to Cell F
1/93	11/93	Bioremediation of Cell F
6/93	1/94	Post-treatment care and backfill of Cell E with clean soil
12/93	3/94	Demobilization of treatment equipment from Cell F
2/94	11/94	Post-treatment care and backfill of Cell F with clean soil

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

The ROD specified maximum allowable concentrations for five contaminants in lagoon subsoils and sludges at the French Ltd. site. [1]

These contaminants, listed in Table 4, were specified in the ROD as indicator compounds and the cleanup goals shown above were developed based on the results from a risk assessment using a 1×10^{-5} excess lifetime cancer risk factor. Bioremediation was required until analytical results for all sampling points (nodes) were in compliance with site remediation cleanup goals for two consecutive sampling events. Each sample from every composited node sample was required to meet the cleanup goals. [1, 9]

In addition, the ROD specified an action level for total VOCs in ambient air of 11 ppm for 5 minutes at any time during treatment. The action level applied to the ambient air at the site boundary for the 35 VOCs listed in Table 5. [9]

Table 4. Cleanup Goals for Soils and Sludges [1]

Contaminant	Maximum Allowable Concentration (mg/kg)
Benzo(a)pyrene	9
Total PCBs	23
Vinyl Chloride	43
Arsenic	7
Benzene	14

Table 5. VOCs Required to be Measured in Ambient Air [9]

Acetone	1,1-Dichloroethane
Benzene	1,2-Dichloroethane
Bromodichloromethane	Trans-1,2-Dichloroethene
Bromoform	Ethylbenzene
Bromomethane	2-Hexanone
2-Butanone	Methylene chloride
Carbon disulfide	4-Methyl-2-pentanone
Carbon tetrachloroide	Styrene
Chlorobenzene	Tetrachloroethene
Chloroethane	1,1,2,2-Tetrachloroethane
2-Chloroethylvinylether	Toluene
Chloroform	Total Xylenes
Chloromethane	1,1,1-Trichloroethane
Dibromochloromethane	1,1,2-Trichloroethane
1,2-Dichloropropane	Trichloroethene
cis-1,3-Dichloropropene	Vinyl acetate
Trans-1,3-Dichloropropene	Vinyl Chloride
1,1-Dichloroethene	

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data

Treatment performance was monitored using subsoil and sludge samples and mixed liquor samples. To assess compliance with cleanup goals, subsoil and sludge samples were collected from 52 grid sampling locations in Cell E and 68 locations in Cell F. During each bioremediation progress measurement sampling event, approximately 50% of these locations were sampled. Sludge and subsoil samples were taken from the lagoon bottom using a core sampling device from a workboat. An OVM-PID meter was used to measure volatile organic concentrations along the surface of the core. The sludge sample was taken from the sludge layer at the point of highest volatile organic concentration. The subsoil sample was collected from a composite of the subsoil from the upper 4-foot layer of subsoil collected in each core. [9]

Tables 6 and 7 show the average concentrations measured in the subsoil and sludge during the bioremediation treatment of Cells E and F, respectively. The values shown on these tables are for composited samples collected during the treatment process.

The five indicator compounds showed reductions in concentrations over the course of treatment. For example, benzene was reduced from 608.0 mg/kg to 4.4 mg/kg in Cell E, and from 393.3 mg/kg to 5.2 mg/kg in Cell F. [13-20, 24-31]

Mixed liquor samples were collected at two locations in each treatment cell, and analyzed for the parameters listed in Table 8 to monitor the treatment performance. One sample was taken from the middle of the walkway across the sheetpile wall that separates the two treatment cells and a second sample was taken at the middle of treatment cell using the site workboat for access to the location. [9] The mixed liquor contained about 5-10% solids during operation. [38]

An ambient air monitoring program was implemented to monitor potential releases of VOCs from the bioremediation process. Ambient air monitoring was completed using automatic instrumentation equipment placed at strategic points around the operating bioremediation treatment cell. Table 9 shows total VOC concentrations, reported as maximum organic vapor analyzer (OVA) readings at various locations around the site boundary by month for January 1992 through August 1993. Total VOC concentrations ranged from 0.3 to 1.6 ppm, which were lower than the action level of 11 ppm specified in the ROD. [9]

Ambient air monitoring was also completed using continuous sampling at points between the bioremediation cell and the three nearest potential receptors. Samples were analyzed daily to provide a time-integrated measurement of 35 VOCs and to provide data, on a weekly basis, to calculate the health risk to the nearest receptors. As reported by FLTG, the health risk resulting from air emissions was within U.S. EPA-approved health risk criteria. [9]

Performance Data Assessment

The treatment results, shown in Tables 6 and 7, indicate that the cleanup criteria were met within 10 months from the start of treatment for Cell E (October 1992) and 11 months for Cell F (November 1993). For individual constituents, cleanup goals were achieved the soonest for vinyl chloride (4 months in Cell E, 1 month in Cell F) and total PCBs (4 months in Cell E, 1 month in Cell F); benzo(a)pyrene required the longest amount of treatment time to meet the cleanup goals.

Concentrations were reduced to below detection limits in Cell E and 6.6 mg/kg in Cell F for vinyl chloride; 4.4 mg/kg in Cell E and 5.2 mg/kg in Cell F for benzene; and 6.0 mg/kg in Cell E and 6.8 mg/kg in Cell F for benzo(a)pyrene. In addition, the ambient air monitoring data show no exceedances of the established criteria for releases of VOCs. These data, in combination with the operating data, indicate that organic compounds, including vinyl chloride, benzene, and

TREATMENT SYSTEM PERFORMANCE (CONT.)

Table 6. Cell E Treatment Performance Data - Average Subsoil and Sludge Results [13-20]

Sampling Date*	Project Day	Indicator Compounds: Vinyl Chloride (mg/kg)	Benzene (mg/kg)	Benzo(a)pyrene (mg/kg)	Total PCBs (mg/kg)	Arsenic (mg/kg)	TPH (ppm)	Solids (%)	Volatile Solids (%)
Cleanup Criteria		**43.00**	**14.00**	**9.00**	**23.00**	**7.00**			
4/13/92	96	314.80	608.00	BDL(1000)	77.00	9.20	458.00	55.00	16.30
4/27/92	110	29.40	162.30	BDL(1000)	6.40	20.30	788.20	69.70	12.80
5/11/92	124	32.50	119.80	BDL(1000)	NA	121.20	40740.00	68.10	14.00
6/1/92	145	0.50	10.80	BDL(1000)	11.40	125.40	184.40	72.70	12.80
6/22/92	166	0.80	25.60	BDL(1000)	15.80	NA	24900.00	79.40	5.40
7/13/92	187	1.20	41.90	14.40	13.40	17.90	14066.00	79.10	8.50
7/27/92	201	BDL(25.5)	18.80	27.40	10.30	84.70	4193.30	75.90	6.80
8/10/92	215	BDL(16.8)	16.30	BDL(474)	13.20	61.80	12576.00	75.30	6.50
8/24/92	229	BDL(24.0)	10.90	28.00	3.10	10.20	9564.00	80.20	4.50
9/3/92	239	1.20	7.30	33.70	8.70	1.20	8566.70	80.20	4.10
9/17/92	253	4.80	12.10	26.30	14.70	1.40	10900.00	75.20	4.20
10/6/92	272	4.30	7.50	3.10	7.40	BDL(1.0)	NR	NR	NR
10/9/92	275	BDL(16.0)	7.30	8.70	6.80	BDL(2.0)	NR	NR	NR
10/23/92	289	BDL(16.0)	6.00	7.40	4.60	BDL(1.0)	NR	NR	NR
10/27/92	293	BDL(16.0)	5.80	4.80	6.00	1.10	NR	NR	NR
10/29/92	295	BDL(16.0)	4.40	6.00	7.9	NR	NR	NR	NR

**Remediation began in January 1992.*
BDL - Below Detection Limit (value in parentheses is detection limit).
NR - Not Reported.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Table 7. Cell F Treatment Performance Cata - Average Subsoil and Sludge Results [24-31]

Sampling Date*	Project Day	Indicator Compounds					TPH (ppm)	Solids (%)	Volatile Solids (%)
		Vinyl Chloride (mg/kg)	Benzene (mg/kg)	Benzo(a)pyrene (mg/kg)	Total PCBs (mg/kg)	Arsenic (mg/kg)			
Cleanup Criteria		**43.00**	**14.00**	**9.00**	**23.00**	**7.00**			
2/10/93	38	0.30	393.30	32.30	10.80	3.10	25585.70	80.70	9.40
3/10/93	66	3.50	51.20	19.60	7.10	4.10	19675.00	72.60	8.70
4/7/93	94	17.60	35.30	29.80	18.30	2.30	19780.00	74.00	9.10
4/20/93	107	13.30	24.40	10.40	3.80	3.00	13550.00	73.90	14.90
5/6/93	123	15.30	27.80	16.10	5.40	4.00	12778.80	75.80	6.70
5/18/93	135	17.00	21.00	11.10	4.10	2.20	9979.30	75.80	6.10
6/1/93	149	17.00	7.40	9.60	3.30	2.00	10687.50	77.50	6.70
6/15/93	163	35.60	12.40	14.50	5.00	2.60	12333.80	77.90	6.50
6/17/93	165	18.10	10.20	10.10	3.30	2.80	9376.30	77.80	6.60
6/29/93	177	16.60	14.80	11.50	4.40	1.80	8738.80	77.60	5.50
7/1/93	179	16.60	12.60	14.40	4.20	2.80	8957.50	77.00	6.30
7/13/93	191	24.60	12.90	11.30	4.30	3.60	9507.50	76.40	5.80
7/27/93	205	13.90	7.30	10.00	2.50	2.10	9100.00	77.70	5.40
8/10/93	219	17.30	10.10	11.00	2.50	2.90	9462.50	78.70	5.00
8/24/93	233	16.00	11.80	7.80	2.90	2.30	5868.80	79.90	5.10
9/6/93	246	12.00	7.20	6.60	2.80	4.00	5731.30	79.90	4.80
9/21/93	261	6.40	4.40	6.90	2.80	1.80	5225.00	80.40	3.40
9/23/93	263	6.60	5.20	6.80	3.40	2.50	4862.50	80.40	4.40

*Remediation began in January 1993.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (cont.)

benzo(a)pyrene were removed from the lagoon via biodegradation. According to the FLTG, available data indicate that PCBs were biodegraded in the slurry-phase system to concentrations below the action levels established for French Ltd. Also, according to the FLTG, arsenic and metals were not biodegraded; they were dispersed in the final residue. [38]

Table 9. Total VOC Readings by Month [37]

Month	Total VOC* (ppm)
January 1992	1
February 1992	0.9
March 1992	0.9
April 1992	1.1
May 1992	1.1
June 1992	1.3
July 1992	1
August 1992	0.8
September 1992	0.9
October 1992	0.6
November 1992	1.6
December 1992	0.4
January 1993	0.5
February 1993	0.4
March 1993	0.6
April 1993	0.5
May 1993	0.6
June 1993	0.5
July 1993	0.4
August 1993	0.3

**Total VOC concentrations as maximum OVA readings.*

Performance Data Completeness

The available data characterize the concentration of five contaminants in the subsoil and sludge over the course of the bioremediation, as well as three potential indicator parameters (TPH, % solids, and % volatile solids). Data are not available to match these treated concentrations with concentrations in the cells before treatment. The first samples taken after mixing began were at Day 96 for Cell E and Day 38 for Cell F.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Quality

Quality assurance/quality control (QA/QC) procedures for sampling and analytical activities are outlined in the second volume of the Remedial Action Plan, entitled Quality Assurance Plan. Monthly progress reports prepared by the FLTG include discussions of QA/QC issues during the remediation. EPA took split samples of confirmation samples after the cleanup objectives had been met. According to monthly progress reports, there were no discrepancies between the samples taken by FLTG and EPA.

TREATMENT SYSTEM COST

Procurement Process [38, 39]

FLTG contracted with ENSR to design the slurry-phase bioremediation system, and with Bechtel Corporation to construct the lagoon remediation system. FLTG and ENSR selected several key equipment vendors by competitive bidding, including Praxair, Dredging Supply, ITT Flygt, Sala, and Siemens. FLTG directly hired personnel and support staff to operate and maintain the remediation systems.

All contracts were competitively bid. Contracts were awarded based on commercial terms and qualifications. Contract types included lump sum, fixed unit price, and cost reimbursable depending on the scale of work and degree of definition.

Treatment System Cost

According to the FLTG, the total cost of remediating the soil and sludge in the lagoon at French Ltd. was $49,000,000, including costs for technology development, project management, EPA oversight, and backfill of the lagoon. The $49,000,000 total cost was broken down into nine project elements by the RPM and FLTG, as shown in Table 10. [37, 39]

The FLTG also provided a breakdown of the costs according to the format for an interagency Work Breakdown Structure (WBS), as shown in Tables 11, 12, and 13. The WBS is being used as a format for standardizing reporting of costs across projects. No additional information on the specific items included in each cost element shown in Tables 11, 12, and 13 were provided by the FLTG. [38]

As shown in Tables 11, 12, and 13, approximately 55% of the project costs were for activities directly associated with treatment, 34% were for before-treatment activities, and 11% for after-treatment activities. The $26,900,000 in costs for activities directly associated with treatment corresponds to approximately $90/ton of sludge and soil treated (for 300,000 tons treated).

Table 10. Breakdown of Project Costs by the RPM and FLTG [37, 39]

Project-Element	Cost ($)
Development and Pilot-Scale Work	12,200,000
Floodwall	2,300,000
Operation, Maintenance, Analytical	22,900,000
Dewatering	1,000,000
Fixation	400,000
Technical Support	2,900,000
Administrative	3,100,000
Demobilization	1,900,000
EPA Oversight	2,300,000
Total	49,000,000

TREATMENT SYSTEM COST (CONT.)

Treatment System Cost (cont.)

Table 11. Treatment Activity Cost Elements Provided by FLTG According to the WBS [38]

Cost Elements (Directly Associated With Treatment)	Cost (dollars)	Actual or Estimated (A) or (E)
Solids Preparation and Handling	2,200,000	A
Liquid Preparation and Handling	2,800,000	A
Vapor/Gas Preparation and Handling	4,600,000	A
Pads/Foundation/Spill Control	300,000	A
Mobilization/Set Up	1,200,000	A
Startup/Testing/Permits	1,300,000	A
Training	900,000	A
Operation (short-term - up to 3 years)	13,600,000	A
TOTAL TREATMENT ACTIVITY COST	26,900,000	A

Table 12. Before-Treatment Cost Elements Provided by FLTG According to the WBS [38]

Cost Elements	Cost (dollars)	Actual or Estimated (A) or (E)
Mobilization and Preparatory Work	1,100,000	A
Monitoring, Sampling, Testing, and Analysis	4,900,000	A
Site Work	4,000,000	A
Surface Water Collection and Control	2,300,000	A
Groundwater Collection and Control	1,100,000	A
Air Pollution/Gas Collection and Control	1,800,000	A
Solids Collection and Containment	600,000	A
Liquids/Sediments/Sludges Collection and Containment	800,000	A
Drums/Tanks/Structures/Miscellaneous Demolition and Removal	200,000	A
TOTAL BEFORE-TREATMENT COST	16,800,000	A

Table 13. After-Treatment Cost Elements Provided by FLTG According to the WBS [38]

Cost Elements	Cost (dollars)	Actual or Estimated (A) or (E)
Decontamination and Decommissioning	1,300,000	A
Disposal (other than commercial)	400,000	A
Disposal (commercial)	400,000	A
Site Restoration	2,300,000	A
Demobilization (other than treatment unit)	400,000	A
Other (topsoil and revegetation)	800,000	A
TOTAL AFTER-TREATMENT COST	5,600,000	A

TREATMENT SYSTEM COST (CONT.)

Cost Data Quality

The cost information presented above represents actual costs for this application. Cost information was available for activities directly associated with treatment, and for elements associated with before-treatment and after-treatment activities.

PRP and Vendor Input [38-40]

According to the FLTG, the costs for future, similar applications are expected to be similar to those incurred for French Ltd., and depend on site-specific chemical and physical conditions. The key factors which affect costs of bioremediation systems are oxygen and nutrient supply.

According to ENSR, costs for a second generation system that did not require pilot studies or sheet pile work would be about 40% less than those incurred at French Ltd.

According to Praxair, the cost of oxygen at future similar sites will be affected by the location of the site (local power rates affect oxygen production costs), the distance from the oxygen-producing plant (distribution costs), the rate of oxygen consumption (site supply system requirements), and the duration of the oxygen use (amortization of installation/removal costs).

The cost of the MixFlo system will be affected by the rate of oxygen dissolution (capital and operating costs) and the oxygen dissolution characteristics of the slurry.

As a result of the application at the French Ltd. site, Praxair, Inc. has developed a new oxygen dissolution technology—the In-Situ Oxygenator™. This system dissolves oxygen and suspends solids using approximately 25% of the power required by MixFlo or by air-based aeration systems while maintaining the high-oxygen utilization efficiency of the MixFlo technology.

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- Treatment costs, including project management, pilot studies, technology development, EPA oversight, and backfill of the lagoon, were approximately $49,000,000.
- Fifty-five percent of the costs ($26,900,000) were for activities directly associated with treatment, such as solids preparation and handling, liquid preparation and handling, vapor/gas preparation and handling, pads/foundations/spill control, mobilization/set up, startup/testing/ permits, training, and operation (short-term - up to 3 years).
- The $26,900,000 in costs for activities directly associated with treatment corresponds to approximately $90/ton of sludge and soil treated (for 300,000 tons treated).
- Excavation was not required for treatment at French Ltd., and the relatively large quantity of sludge and soil treated at this site resulted in economies-of-scale.

Performance Observations and Lessons Learned

- Performance data indicated that the cleanup goals for the five target compounds (benzo(a)pyrene, PCBs, vinyl chloride, arsenic, and benzene) were met within 10 months for treatment of one cell and 11 months for the other cell.

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Performance Observations and Lessons Learned (cont.)

- Operations data show that vinyl chloride, benzene, and benzo(a)pyrene were biodegraded in this application. Concentrations were reduced to below detection limits in Cell E and 6.6 mg/kg in Cell F for vinyl chloride; 4.4 mg/kg in Cell E and 5.2 mg/kg in Cell F for benzene; and 6.0 mg/kg in Cell E and 6.8 mg/kg in Cell F for benzo(a)pyrene.
- Air emission limits were not exceeded during this application.
- The MixFlo system maintained a dissolved oxygen level in the slurry of 2.0 mg/L, mixed the slurry, and minimized air emissions.

Other Observations and Lessons Learned

- The treatability study predicted removal of volatile organic compounds and polynuclear aromatic hydrocarbons during sludge and soil mixing, and extended aeration within 275 project days. Full-scale treatment performance data indicated that the cleanup goals for the indicator compounds were met within this time period.
- The treatability study demonstrated the feasibility of bioremediation for VOCs and SVOCs in soil and sludge within the lagoon without exceeding air emissions limitations.

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ACKNOWLEDGMENTS

Analysis Preparation

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APPENDIX A - TREATABILITY STUDY RESULTS

Identifying Information	
French Limited Superfund Site Crosby, Texas	CERCLIS#: TXD980514814 ROD Date: 24 March 1988
Historical Activity at Site - SIC Codes:	4953 (Waste Management-refuse systems; sand and gravel pit disposal)
Historical Activity at Site - Management Practices:	Disposal Pit
Site Contaminants:	Polynuclear aromatic hydrocarbons: halogenated semivolatiles; non-halogenated volatiles: metals; and nonmetallic elements
Type of Action:	Remedial
Did the ROD/Action Memorandum include a contingency on treatability study results?	No
Treatability Study Information	
Type of Treatability Study:	Pilot
Duration of Treatability Study:	April 1987 to April 1988
Media Treated:	Soil and Sludge (in situ)
Quantity Treated:	0.5-acre cell
Treatment Technology:	Slurry-Phase Bioremediation
Target Contaminants of Concern:	Volatile Organic Compounds (VOCs) and Semivolatile Organic Compounds (SVOCs)
Conducted before the ROD was signed:	Yes
Additional treatability studies conducted:	Yes (laboratory/bench-scale and tank-scale studies of bioremediation also conducted)
Technology selected for full-scale application:	Yes
Treatability Study Strategy	
Key Operating Parameters Varied:	Different aerators and mixers were used
Treatability Study Results	
Range of Individual VOC Concentrations in Untreated Soil and Sludge Matrix:	Up to 3,500 mg/kg
Range of Individual SVOC Concentrations in Untreated Soil and Sludge Matrix:	Up to 6,000 mg/kg
Range of Treated VOC Concentrations in Soil and Sludge Matrix:	Less than 100 mg/kg
Range of Treated SVOC Concentrations in Soil and Sludge Matrix:	Less than 100 mg/kg
Site Logistics/Contact Information:	
French Ltd. Task Group	Mr. R.L. (Dick) Sloan Project Coordinator FLTG, Incorporated 15010 FM 2100, Suite 200 Crosby, Texas 77532 (713) 328-3541

APPENDIX A - TREATABILITY STUDY RESULTS (CONT.)

IDENTIFYING INFORMATION

Type of Treatability Study: Pilot-scale slurry-phase bioremediation study of sludge and subsoil contaminated with PCBs, benzo(a)pyrene, benzene, vinyl chloride, arsenic, and other VOCs and SVOCs.

TREATABILITY STUDY STRATEGY [8]

Treatability Study Purpose: The purpose of the pilot-scale treatability study was to assess the feasibility of bioremediation of the contaminated lagoon at the site, and to determine the following:

- Whether indigenous microorganisms could be stimulated to destroy the organic waste materials and clean up contaminated soil in a reasonable amount of time;
- How to control air emissions during remediation;
- How to mechanically mix the microorganisms, oxygen, nutrients, and mixed liquor to obtain satisfactory reaction rates; and
- How long the cleanup would take.

Cleanup Goals/Standards: Cleanup goals were not identified for the French Ltd. site at the time of the pilot-scale treatability study.

TREATMENT SYSTEM DESCRIPTION [8]

Treatment System Description and Operation: Earlier tests were performed from late 1986 to early 1987 using two 20,000-gallon reactors to determine if microorganisms could be stimulated to degrade site contaminants in a reasonable amount of time.

Subsequently, a pilot-scale test was operated on a one-half acre cell on the west end of the lagoon between April 1987 through April 1988. The equipment included ambient air control, sparged air aeration, and mixers.

The study included the following operation:

- Aeration of the mixed liquor;
- Nutrient addition to grow the biomass; and
- Shearing of sludges and contaminated soil.

The sludge and soil were sheared so that the contaminants would be brought into contact with the microbes. A swinging-ladder dredge was used to shear the soil and open-faced centrifugal pumps were used for the tarry sludge. Over the course of the pilot test, many different aerators, mixers, and dredges were tested. [8]

Procurement Process/Treatability Study Cost: The cost of the pilot-scale treatability test was $5 million.

TREATABILITY STUDY RESULTS [8]

Operating Parameters and Performance Data: The initial reactor tests showed that the native microorganisms could be successfully stimulated to metabolize the organic waste materials in a reasonable amount of time.

The results of the pilot test showed a reduction in concentration of volatile organic compounds (VOCs) and semi-volatile compounds (SVOCs), as shown in Figure A-1, during the course of the study.

Performance Data Assessment: The results in Figure A-1 show a reduction in concentration of 9 VOCs and 9 SVOCs to concentrations of less than 100 mg/kg for individual VOCs and SVOCs, and that bioremediation is

APPENDIX A: TREATABILITY STUDY RESULTS (CONT.)

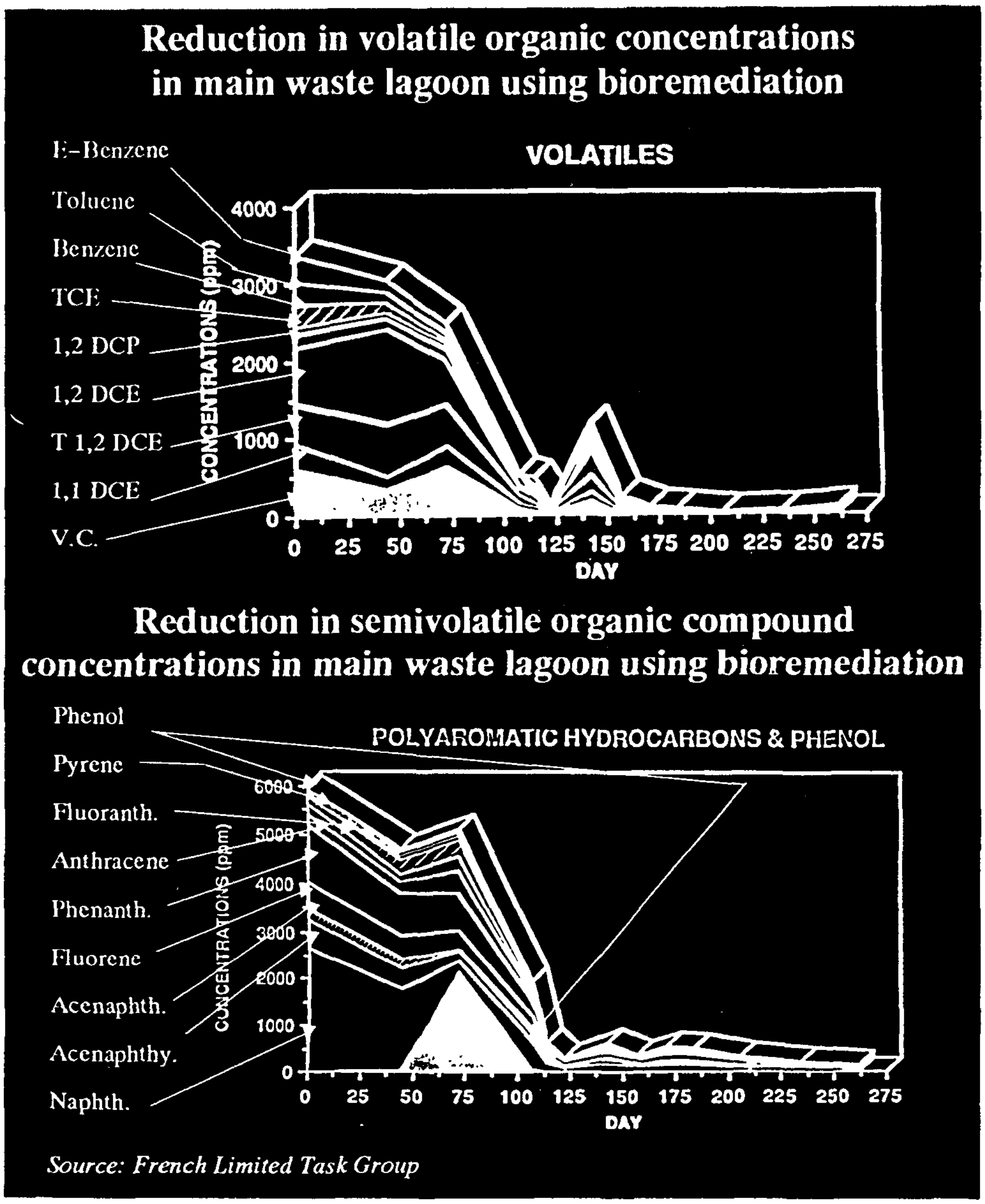


Figure A-1. Reductions in VOC and SVOC Concentrations During Pilot Test [8]

APPENDIX A- TREATABILITY STUDY RESULTS (CONT.)

TREATABILITY STUDY RESULTS (cont.) [8]

a feasible technology for remediation of the soil and sludge in the lagoon. The data indicate that removal of these contaminants occurred within 275 days of soil and sludge mixing and dredging, and extended aeration.

Although no data are available at this time, the results of the pilot test were used in selecting specific equipment and in optimizing operational methods for the full-scale remediation, including control of air emissions and performing mechanical mixing. The shearing equipment chosen allowed two different implements to be attached, one for shearing sludge and the other for shearing soil.

OBSERVATIONS AND LESSONS LEARNED

- The initial reactor tests showed that the native microorganisms could be successfully stimulated to metabolize organic waste materials in a reasonable amount of time.
- The treatability study showed reductions in the concentrations of 9 VOCs and 9 SVOCs from soil and sludge in the lagoon to concentrations less than 100 mg/kg for individual contaminants. These results were achieved within 275 days of sludge and soil mixing and extended aeration.

Low-Intensity Bioventing for Remediation of a JP-4 Fuel Spill at Site 280 Hill Air Force Base, Ogden, Utah (Interim Report)

Case Study Abstract

Low-Intensity Bioventing for Remediation of a JP-4 Fuel Spill at Site 280 Hill Air Force Base, Ogden, Utah

Site Name: Hill Air Force Base, Site 280	**Contaminants:** Total Petroleum Hydrocarbons (TPH) and Benzene, Toluene, Ethylbenzene, Xylenes (BTEX) - Soil TPH concentrations measured as high as 5,040 mg/kg - Soil gas TPH concentrations measured as high as 11,200 ppm	**Period of Operation:** Status - Ongoing Report covers - 12/90 to 6/94
Location: Ogden, Utah		**Cleanup Type:** Full-scale cleanup (interim results)
Vendor: Not Available	**Technology:** Bioventing - System consists of 1 injection well and 10 monitoring wells - Air flow rate on blower discharge ranged from 20 to 117 acfm; operated since 11/93 at 20 acfm - Blower discharge pressure of 2 in. of Hg	**Cleanup Authority:** State: Utah
SIC Code: 9711 (National Security)		**Point of Contact:** William James Remedial Project Manager Hill Air Force Base Ogden, Utah
Waste Source: Spills and other releases of JP-4 jet fuel	**Type/Quantity of Media Treated:** Soil - Soil-gas permeability value - 0.057 darcy - Porosity 30 to 50%; moisture content 1.4 to 18%; air conductivity 4.7 to 7.8 darcies; particle density 0.3 to 0.5 gm/cm^3 and particle diameter 0.8 to 10 mm; soil bulk density 0.37 to 0.48 gm/cm^3; soil organic content 0.08 to 0.86%	
Purpose/Significance of Application: Bioventing to remediate soils contaminated with JP-4 jet fuel.		

Regulatory Requirements/Cleanup Goals:
- No specific cleanup goals established at this time
- Cleanup assessment will be conducted subject to "Guidelines for Estimating Numeric Cleanup Levels for Petroleum Contaminated Soils at Underground Storage Tank Release Sites," which are established by Utah Department of Health

Results:
- Bioventing project was not complete at time of this report
- Respiration rate tests from 4/91 to 11/93 indicate hydrocarbon degradation is occurring
- As of 11/92, soil gas TPH concentration reduced to less than or equal to 2,600 ppm
- Estimates of the mass of contaminants removed have not yet been reported

Cost Factors:
- Total Capital Cost (estimated) - $115,000 (including construction of piping system, buildings, process equipment, and startup)
- Total Annual Operating Cost (estimated over 4 years) - $24,000 (including labor, electricity, lab charges, maintenance, and monitoring)

Low-Intensity Bioventing for Remediation of a JP-4 Fuel Spill at Site 280 Hill Air Force Base, Ogden, Utah (Continued)

Description:
As a result of spills and other releases of JP-4 jet fuel at the 280 Fuel Storage Lot at Hill Air Force Base in Ogden, Utah, soil was contaminated with total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylenes (BTEX). TPH concentrations were reported as high as 5,000 mg/kg in the soil and 11,200 ppm in the soil gas. A low-intensity bioventing system was installed at the site and has been in operation since December 1990. No specific cleanup goals have been established at this time. The final cleanup assessment will be conducted subject to "Guidelines for Estimating Numeric Cleanup Levels for Petroleum Contaminated Soils at Underground Storage Tank Release Sites", which are established by the Utah Department of Health.

The bioventing system includes one injection well (100 ft. depth) and 10 monitoring wells (varying depths). During the operation of this system, the air flow rate of the blower discharge had been varied between 20 and 117 acfm (at a discharge pressure of 2 in. of Hg) in order to optimize air flow rates while eliminating volatilization. Available data from respiration rate tests (4/91 to 11/93) indicate that hydrocarbon degradation is occurring. As of November, 1992, soil gas TPH concentrations had been reduced from 11,200 mg/kg to below 2,600 mg/kg. Estimates of the mass of contaminants removed have not yet been reported.

The estimated total capital cost for this application is $115,000. The total annual operating cost, estimated over 4 years, is $24,000 exclusive of final site characterization. During this application, it was noted that biodegradation is enhanced by maintaining adequate soil oxygen, moisture, and nutrient levels and that estimates of biodegradation are more accurate if oxygen depletion is used instead of carbon dioxide formation. In addition, it was noted that air flow rates can be optimized to low levels ranging from 40 to 67 acfm.

SITE

Operable Unit: Hill Air Force Base, area around the 280 Fuel Storage Lot as shown on Figure 1.
City, State: Ten miles south of Ogden, Utah

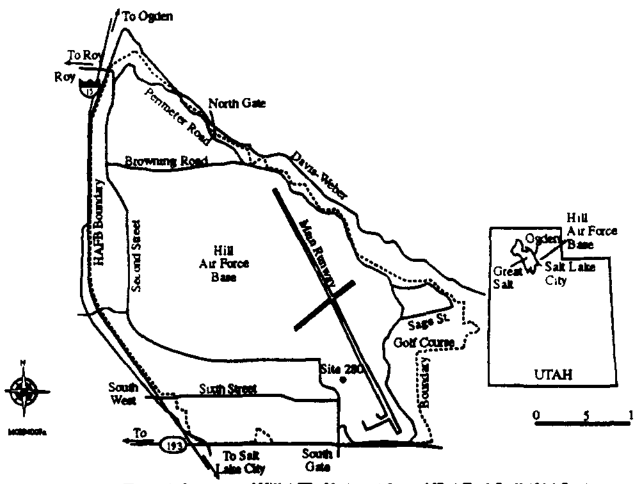


Figure 1. Location of Hill AFB, Utah and Site of JP-4 Fuel Spill (914 Site).

TECHNOLOGY APPLICATION

This summary addresses field application of bioventing and associated investigative methods performed in 1991 and 1992. Remedial activities at the site were carried out by the U.S. Air Force and the USEPA.

SITE CHARACTERISTICS

Site History / Release Characteristics

- Hill Air Force Base has been in operation since 1942, and the 280 Fuel Storage Lot has been in place since 1941.
- In 1989 four underground JP-4 jet fuel storage tanks (25,000 gal. each) were removed and replaced with two above ground tanks (25,000 gal. each).
- The most recent recorded spill in the area occurred in 1982. No other fuel releases are documented; however, others are suspected to have occurred during the life of the system.
- Site remediation began in November 1990. Figure 2 shows a detail of 280 Fuel Storage Lot and various wells and monitoring locations that have been installed.

Contaminants of Concern

- Specific contaminants of greatest concern in the unsaturated zone were: benzene, toluene, xylene, and ethylbenzene (BTEX). Total petroleum hydrocarbon (TPH) concentration was also monitored throughout the remediation due to relative ease of analysis compared to the specific compounds.
- Groundwater was found to be contaminated downgradient of the site. TPH as well as BTEX were found.
- Trichloroethylene was also found in the groundwater but was not a specific target of the bioventing operations.
- The soil vapor at the ground surface was found to have hydrocarbon levels within acceptable limits.

Contaminant Properties

Table 1

Properties of contaminants focused upon during remediation are provided below.

Property	Units	Benzene	Ethylbenzene	Toluene	Xylenes*
Empirical Formula		C_6H_6	C_8H_{10}	C_7H_8	C_8H_{10}
Density @ 20°C	g/cm3	0.88	0.87	0.87	0.87 (avg)
Melting Point	°C	5.5	-95	-95	-47.9 to13.3
Vapor Pressure (20°C)	mm Hg	50	8.5	26	7.7
Henry's Law Constant (atm)(m3)/mol		5.59 X 10-3	6.43 X 10-3	6.37 X 10-3	7.04X 10-3
Water Solubility	mg/l	1,750	152	535	198
Octanol-Water Partition Coefficient;	Kow	132	1410	537	1830
Organic Carbon Partition Coefficient; Koc	ml/g	83	1,100	300	240
Ionization Potential	ev	9.24	8.76	8.5	8.56
Molecular Weight		78.12	106.18	92.15	106.18

All 3 Isomers (M, O, & P)

Nature & Extent of Contamination

Remedial investigation field activities at the site provided TPH and BTEX concentrations as shown in Figures 2, 3, 4 and 5 and as described below.

- Figure 3 shows soil contamination by TPH at several cluster well locations as a function of depth down to the water table as sampled in September 1991. (Note that the wells are not in a straight line and that horizontal distances shown on the figure are the approximate radial distances from the injection well.)
- Figure 4 shows the soil gas TPH concentration in ppm as monitored in September 1991.
- Figure 5 shows the extent of BTEX contamination in the groundwater at the site as monitored in 1992. Note, BTEX plume has migrated downgradient from the fuel tank area.

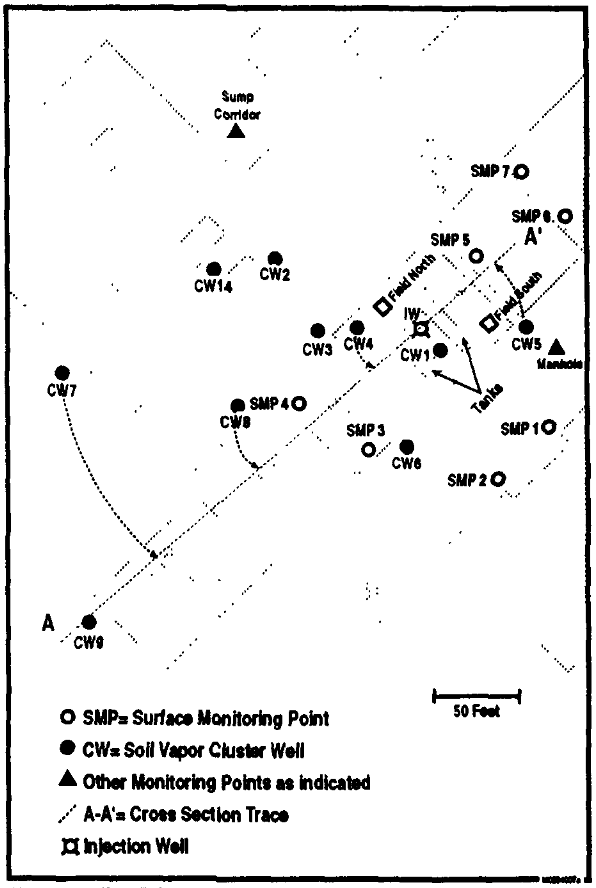


Figure 2. Hill AFB 280 site Map Illustrating the Locations of the Soil-Gas Monitoring Wells (CW), the Suface Monitoring Points (SMP), and the Injection Well (IW).

Contaminant Locations and Geologic Profiles

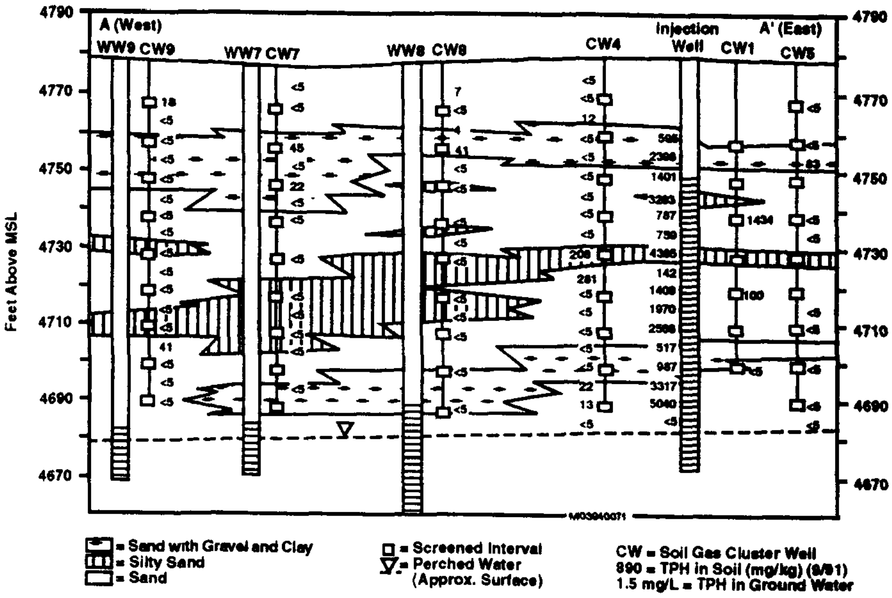


Figure 3. Geological Cross-section of the 280 Site Showing Known Geological Features and Soil Total Petroleum Hydrocarbon Concentrations (mg/kg); Data Collected September 1991.

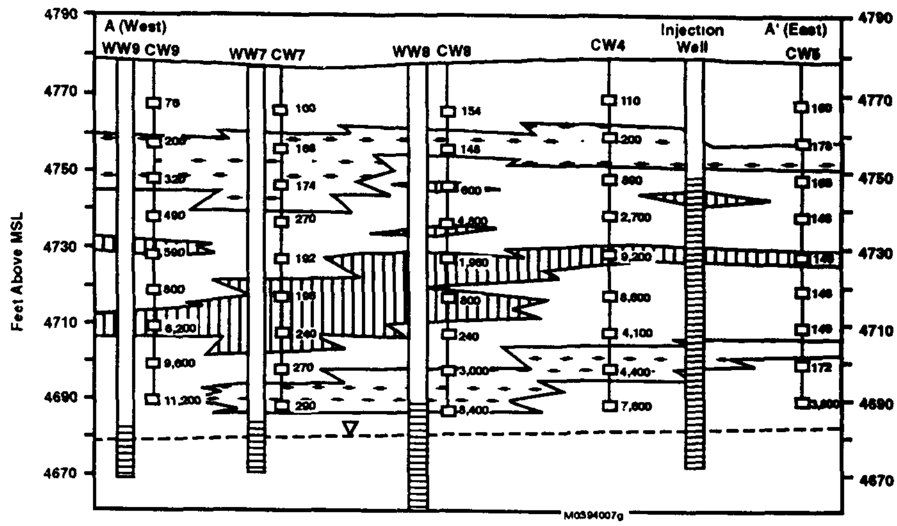


Figure 4. Geological Cross-section of the 280 Site Showing Known Geological Features and Soil-Gas Total Petroleum Hydrocarbon (ppm); Data Collected September 1991.

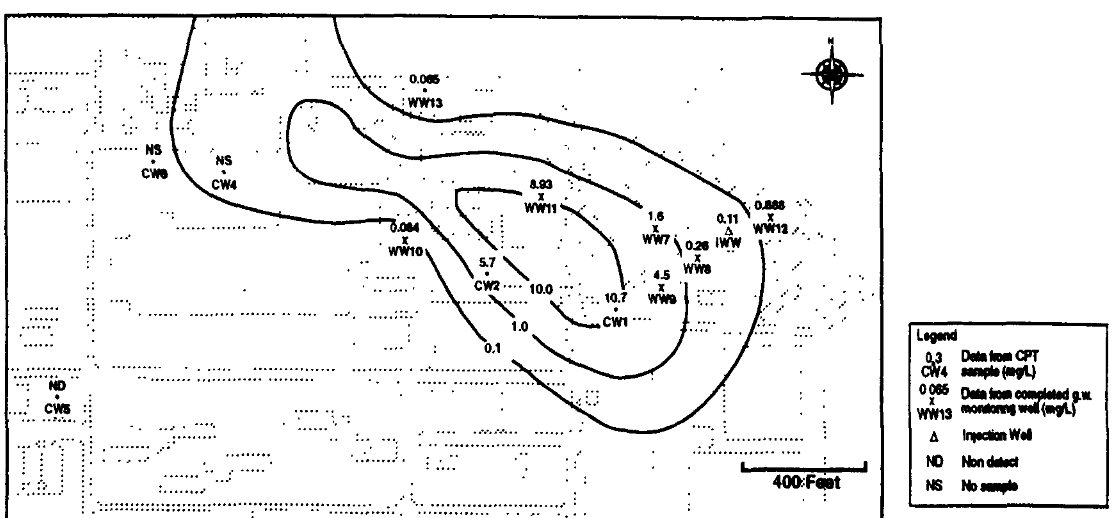


Figure 5. Site 280. Isoconcentration of BTEX Levels Determined from Groundwater Samples Collected During October 1992.

Hydrogeologic Units

- The spill is contained in the Provo formation, which is a delta outwash of the Weber River. The formation consists of mixed sands, silts and gravels with occasional clay lenses. Figures 3 and the similar figures show the typical lithology in cross section.
- The formation extends to a depth of approximately 120 feet and is underlain by a 200 to 300 foot thick clay layer.
- The area contains three aquifers: the shallow aquifer, the Sunset aquifer and the Delta aquifer. The contamination is confined to the shallow aquifer. A water table map of the shallow aquifer (the perched water table) in the vicinity of the 280 Site is shown in Figure 6.
- Groundwater contamination in the shallow aquifer was found but was not an immediate concern to health because the groundwater is present only in discontinuous perched zones. In addition, groundwater is consumed either upgradient from the 280 Site in the shallow aquifer or from the confined Delta or Sunset aquifer.
- The shallow, Sunset and Delta aquifers (in descending order) occur beneath and contiguous to Hill AFB
- The depth to the shallow water table is from 100 to 110 feet bgs.
- The Delta and Sunset aquifers are not contaminated.
- There are buried utilities in the site area. These are not a conduit for contamination movement.
- No potable groundwater supply wells are thought to be affected by the site.

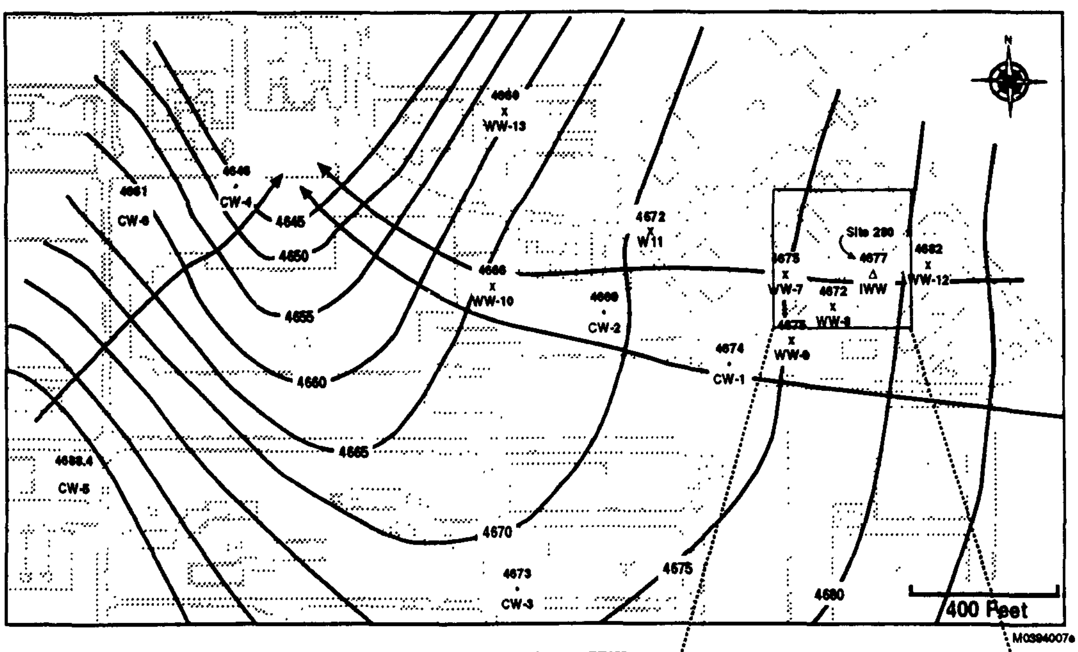
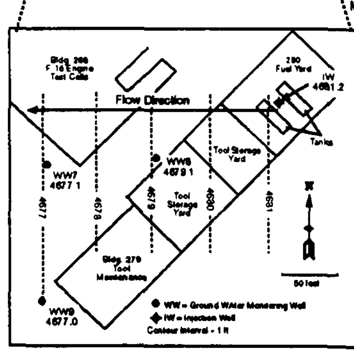


Figure 6. Contour Map for Perched Water Table at Hill AFB Site 280; Data Collected October 1992.



Legend
4688.4 Water table elevation
CW-5 (in ft) measured in CPT
4681.8 Water table elevation (in ft)
WW-12 measured in monitoring well
Δ Injection Well
Groundwater Flow Direction

Site Conditions

- Hill AFB elevation ranges from 5010 to 4570. The elevation in the vicinity of the spill is 4780 feet.
- The area has an arid climate with average ambient temperature of 58°F. The average minimum temperature is 22°F, and the average high is 85°F.
- Precipitation averages 20.1 inches per year. With a maximum monthly precipitation of 6.4 inches occurring in May.
- The direction of groundwater flow at the site is from the east to the west. Locally, at Site 280, the flow takes a northerly direction.

Key Soil or Key Aquifer Characteristics

Table 2

Property	Units	Range or value
Porosity	%	30 to 50
Particle density	g/cm^3	0.3 to 0.5
Soil bulk density	g/cm^3	0.37 to 0.48
Particle diameter	mm	0.8 to 10
Soil organic content	%	0.08 to 0.86
Moisture content	%	1.4 to 18% with average of <6%
Permeability	cm^2	10^{-12} to 10^{-10}
Hydraulic conductivity	cm/s	10^{-12} to 10^{-10} (higher at Site 280 10^{-6} to 10^{-3})
Air conductivity	darcy	4.7 to 7.8
Depth to groundwater	ft	variable due to arid conditions, approximately 110 ft.
Groundwater temperature	°C	10 to 12
Groundwater pH @ 25°C		7.2 to 7.5
Aquifer thickness	ft	10 to 15

TREATMENT SYSTEM

System Description

- The treatment system consists of 1 injection well (IT), 10 monitor wells.
- Although not part of the treatment system, cone penetration tests were used to sample the groundwater at six locations. In addition, the soil vapor at the ground surface was monitored at seven locations (designated SMP on figure 2).
- The rate of diffusion and soil permeability of gas through the vadose zone was studied by several means:
  - Air was injected for several months at a constant rate from a single source and the subsurface pressure distribution and oxygen concentration were monitored.
  - A helium trace test was conducted from December 1992 through February 1993.
- The discharge of the blower is connected to the injection well from which air is distributed through the vadose zone and finally vented through the ground surface to maintain high oxygen concentrations in and remove carbon dioxide from the contaminated soil.

System Operation

- The blower was operated at various flow rates with a discharge pressure of 2 in. Hg. The blower was periodically turned off to allow for installation of additional wells or performance of *in situ* respiration tests.
- The blower flow rate is maintained so that hydrocarbon emission at the ground surface is at an acceptably low concentration.

Well Design Close-up

The well system consists of one injection well (280-IW), soil gas monitoring wells and water monitoring wells as noted the the table below.

Table 3 - Injection and Monitoring Wells

Well Designation	Depth, ft.	Comments	Casing Size, inches	See Figure
280-IW	100	Injection Well	4	2
280-CW1	91	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW2	91	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW3	91	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW4	90	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW5	90	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW6	90	Soil gas monitoring at 10 ft. intervals	1.25	2
280-CW7	90	Deep soil gas monitoring well	4	2
280-CW8	90	Deep soil gas monitoring well	4	2
280-CW9	90	Deep soil gas monitoring well	4	2
280-WW7	107	Screened 5 ft. above and 10 ft. below water table and soil gas monitoring at 2.5, 5, 7.5, and 10 ft.	4	6
280-WW8	125	Screen from 90 ft. to 125 ft. and soil gas monitoring at 2.5, 5, 7.5, and 10 ft.	4	6
280-WW9	110	Screened 5 ft. above and 10 ft. below water table and soil gas monitoring at 2.5, 5, 7.5, and 10 ft.	4	6
280-WW10	124	Water Sampling Well	4	6
280-WW11	115	Water Sampling Well	4	6
280-WW12	109.5	Water Sampling Well	4	6
280-WW13	124	Water Sampling Well	4	6
280-WW13	139	Water Sampling Well	4	6
280-WW14	92	Soil gas monitoring at 2.5, 5, 7.5, and 10 ft. Than each 10 ft.	1.25	2

Key Design Criteria

No specific design criteria were established in the document. However, for bioventing operations, key design criteria would include:

- vadose zone air conductivity;
- soil moisture content;
- soil gas oxygen concentration at monitor wells;
- soil nutrient concentration; and
- hydrocarbon composition in the soil;

Key Monitored Operating Parameters

- Total blower flow rate in acfm (actual cubic feet per minute - continuous measurement).
- Soil moisture content (intermittent measurement).
- Soil TPH content (intermittent measurement).
- Air pressure in the vadose zone.
- Soil vapor hydrocarbon concentration (intermittent measurement).
- Soil vapor % oxygen content (intermittent measurement).
- Soil vapor % carbon dioxide content (intermittent measurement).
- Concentration of helium in the vadose zone.

PERFORMANCE

Performance Objectives

- Remediate the site.
- Optimize the airflow rates to maximize bioremediation while eliminating volatilization.
- Determine the affect of bioventing at the site.
- Determine airflow parameters in the vadose zone.

Treatment Plan

- A study was conducted to determine the extent of contamination at Site 280 by taking soil and gas samples in a number of wells. (See Figures 3 through 5.)
- A pilot scale , low-level bioremediation, treatability study was conducted for site characterization.
- *In situ* respiration tests were performed to determine the effectiveness of each air injection flow rate step in promoting biodegradation. Soil gas O_2 monitoring was used to calculate the mass of hydrocarbon degraded in this phase.
- The extent of site contamination was determined by taking soil samples in the wells at five foot depth intervals and the TPH and BETX concentrations were determined by gas chromatography.
- The treatment of site 280 is ongoing and not complete as of June 1994.

Preliminary Results

- Figures 7 shows the results of the preliminary respiration test at monitor wells CW4, CW5, CW7, CW8 and CW9. Oxygen was consumed at all monitoring the wells tested. This indicates biological degradation occurring when oxygen levels are replenished continuously.

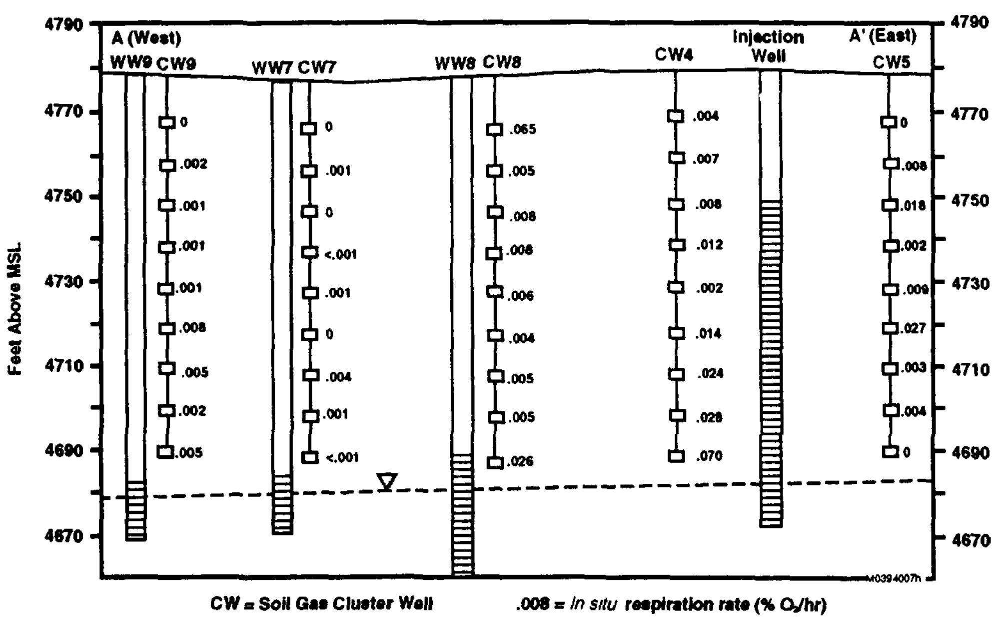


Figure 7. Preliminary In Situ Respriation Profile, September 1992.

Operational Performance

Volume of air circulated

- The following table show the air flow rates overtime and related activities.

Table 4 - Air Injection Flow Rates	
Oct. '90 – Dec. '90	Wells 280-IW, CW-1, CW-2 & CW-3 Constructed.
Dec. '90 – Apr. '91	Air injection at 67 acfm.
Apr. 91 – May '91	No air injection - respiration test.
May '91 – July '91	Air injection at 67 acfm.
July '91 – Aug. '91	well construction.
July '91 – Sept. 91	Blower off - Drilling.
Sept '91 – Sept. '92	Air injection at 67 acfm.
Sept. '92– Oct. '92	No air injection - in situ respiration test.
Aug. '92 – Oct. '92	CPT construction.
Sept. '92	SMP construction.
Oct. '92	280-WW well construction.
Oct. '92 – Dec. '92	Air injection at 45 acfm.
Dec. '92 – Feb. '93	Helium tracer test. Air injection at 67 acfm.
Feb. '93 – Apr. '93	Air injection at 67 acfm.
Apr. '93 – June '93	Air injection at 40 acfm.
June '93 – July '93	No air injection - in situ respiration test.
July '93 – Oct. '93	Air injection at 117 acfm.
Oct. '93 – Nov. '93	No air injection - in situ respiration test.
Nov. '93 – present	Air injection at 20 acfm.

- Figure 8 shows the concentration of soil gas TPH in November 1992, after about 1 1/2 years of blower operation at 67 acfm.

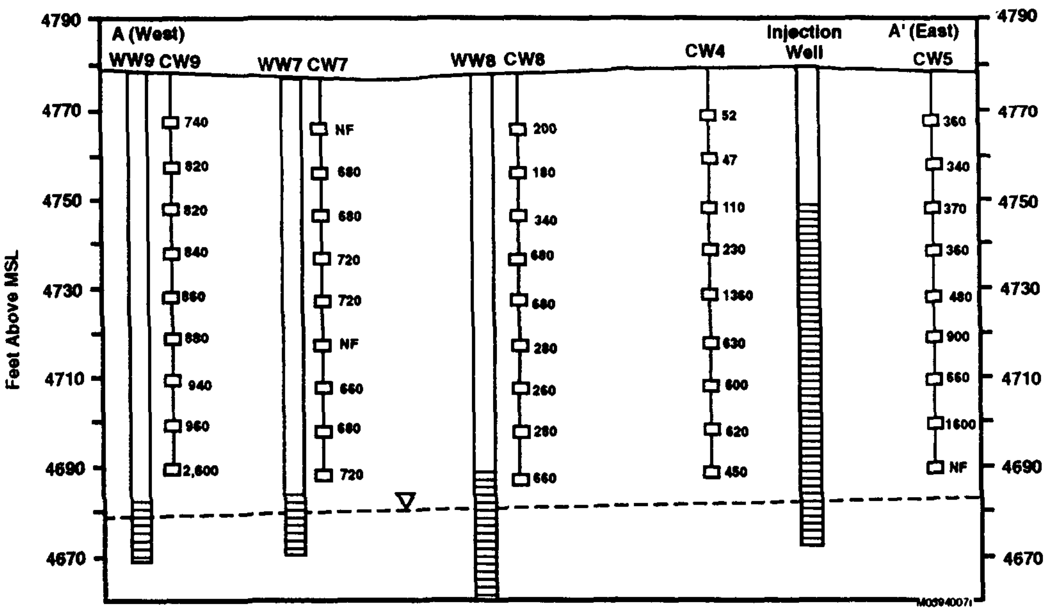


Figure 8. Soil-Gas Total Petroleum Hydrocarbon Concentrations (ppm); November 1992.

- Figures 9 and 10 show the concentration of soil gas oxygen and carbon dioxide, respectively, in November 1992, after about 1 1/2 years of blower operation at 67 acfm.

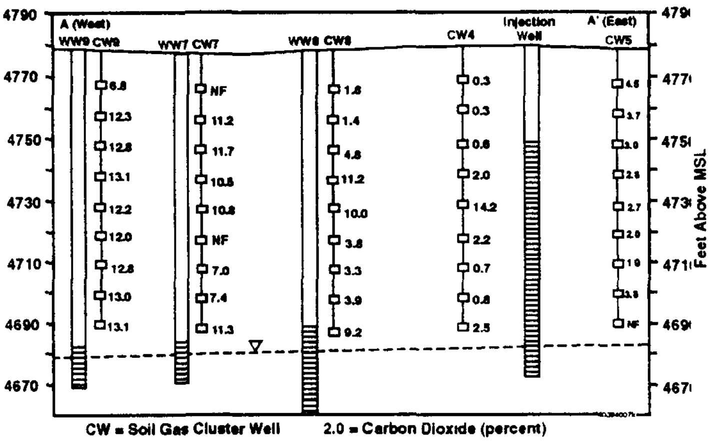


Figure 10. Soil-Gas Carbon Dioxide (percent); November 1992.

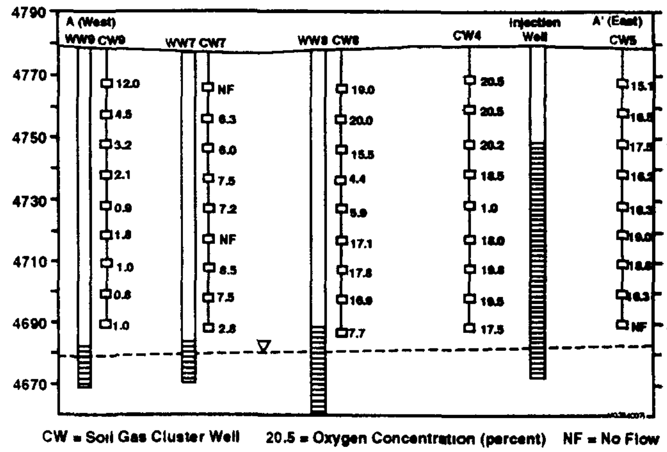


Figure 9. Soil-Gas Oxygen (percent): November 1992.

- The soil vapor TPH concentration at the surface did not appreciably change when the blower was on or off.

Treatment Performance

- Figure 12 shows the results of the respiration or biodegradation rate (mg/kg/day) tests for one well at different times during the test period, April 1991 through November 1993. This is considered representative for the site. These data indicate that the hydrocarbons are being destroyed over time.

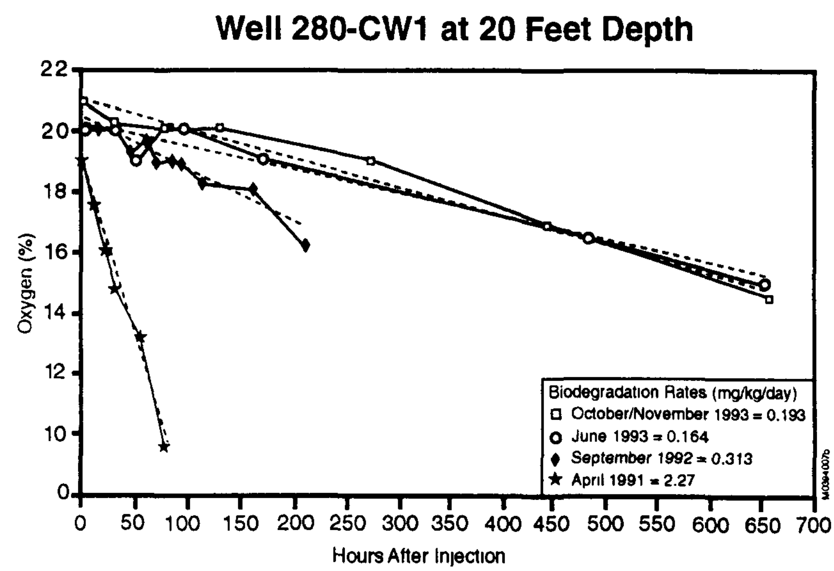


Figure 11. Soil-Gas Monitoring Well 280-CW1 (20 Feet) Biodegradation Data Comparison.

Surface-Emission Testing

- Surface Emission of hydrocarbons were tested for both periods of when the blower was operating and when it was not. Separate sample points were installed for this purpose.
- No significant difference was found between the air-injection and no-air-injection periods.

Soil-Gas Permeability and Radius of Influence

- Based on the air injection and pressure monitoring, the soil-gas permeability value was calculated as 0.057 darcy.
- The radius of influence, based on the air injection test, was estimated to be approximately 200 ft.
- Table 6 is the estimated permeability of the vadose zone at various depths based on the helium test program.

Table 5
Estimated Soil Permeabilities In Vadose Zone
From Helium Test

Depth from Ground Surface (ft)	Permeability (darcy)
30	7.8
40	4.7
50	4.8
60	4.8
70	6.0
80	4.8
90	4.3
Average ± St. Dev.	5.5 ± 1.2

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Total Pounds Contaminants Removed

- The project is not complete at the date of this report nor has the final report been issued. Estimates of the contaminants removed have not been reported as yet.

System Downtime

- The only downtime reported has been associated with the installation of wells, sample points or helium injection equipment was installed. See Table 5, Air Injection Flow Rates

COST

Capital Cost (Estimated)

Construction of Piping System	$100,000
(Construction of Wells and Equipment Costs)	
Buildings and Structures	N/A
Process Equipment	$4,000 to $5,000
(piping and 2.5 HP blower)	
Startup Costs	$10,000
Total Capital Cost	$115,000
Annual Operating Costs (Estimated)	
Electricity (@ $0.07/Kwhr) ($1,500 per year for 4 years)	$6,000
Labor	$40,000
Laboratory Charges	$20,000*
Maintenance Labor & Parts	$3,000 to $5,000
Monitoring (per year)	$25,000
(soil gas and in situ respiration)	
Total (four year O&M estimate*)	$96,000
Total Annual Operating Cost (Estimated over 4 years)	$24,000

** not including final site characterization.*

REGULATORY / INSTITUTIONAL ISSUES

- The site cleanup assessment will be conducted subject to "Guidelines for Estimating Numeric Cleanup Levels for Petroleum-Contaminated Soil at Underground Storage Tank Release Sites", which are criteria published by the Utah Department of Health.
- The numerical levels are assigned based on the source of the spill (gasoline, diesel, or waste oil) and the environmental sensitivity of the area. The jet fuel has physical characteristics which lie between those for gasoline and diesel fuel. The RCL's will be derived from the criteria for these listed fuels.

Target Cleanup Levels/Criteria:

To be established later.

SCHEDULE

Table 6 - Schedule for Hill AFB, Building 280 Low-Intensity Bioremediation Activities

Task	Date
Installation of Initial Soil Gas Wells and Collection and Analysis of soil Samples	Nov. 1990 to Dec. 1990
Air Injection Installed	Dec. 15, 1990
Gas Flow Rate Test #1	Dew. 1990 to Apr. 1991
Air Injection Turned Off	Apr. 23. 1991
In Situ Respiration Test #1	Apr. 1991
Installation of Additional Soil Gas Wells	July 1991
Collection and Analysis of Soil Sample	July 1991
Air Injection Reinitiated	Sept. 5, 1991
Gas Flow Rate Test #2	Sept. 1991 to Sept. 1992
In Situ Respiration Test #2	Sept./Oct. 1992
Tracer Test	Dec. 1992 to Feb. 1993
Gas Flow Rate Test #3	Oct. 1992 to June 1993
Second Annual Report	Apr. 1993
In Situ Respiration Test #3	June/July 1993
Gas Flow Rate Test #4	July to Sept. 1993
In Situ Respiration Test #4	Oct./Nov. 1993
Gas Flow Rate Test #5	Nov. 1993 to Apr. 1994
EPA Final Report	January 1994
In Situ Respiration Test #5	April/May 1994
Final Site Characterization	Aug. 1994
Hill AFB Final Report	Nov. 1994

LESSONS LEARNED

- Care must be taken to insure that laboratory test methods are consistent throughout the project so results may be compared throughout the test.

Key Operating Parameters

- Biodegradation is enhanced by adequate soil oxygen, moisture and nutrient level.
- Air Flow rates can be optimized to low levels, 40 to 67 acfm in this test.

Technology Limitations

- Bioventing is limited to hydrocarbons that can be degraded by the local bacteria. In addition, sufficient soil oxygen, moisture and nutrients are required.
- Estimates of biodegradation are more accurate if oxygen depletion rather than carbon dioxide formation is used. Various carbon dioxide sinks exist in the system. These would include biomass, solubility in water, and reaction with the soil. Oxygen is not as sensitive to these sinks.
- Soil chemistry criteria should be developed to establish when the application of nutrients would be beneficial to the bioventing process.

SOURCES

Major Sources for each Section

Site Characteristics:	Source #s 1, 2, 3 (from list below)
Treatment System:	Source #s 1, 4, 5
Performance:	Source #s 1, 4, 5
Cost:	Source #s 6
Regulatory/Institutional Issues:	Source #s 1, 4, 5
Schedule:	Source #s 1
Lessons Learned	Source #s 1, 4

List of Sources and Additional References

1. *Final Report to U.S.E.P.A.; Bioremediation of Hazardous Wastes at CERCAL and RECLA sites:* Hill AFB 280 Site, Low-Intensity bioreclamation: January 1994.
2. *Basics of Pump-and-Treat Ground-Water Remediation Technology,* EPA-600/8-90/003, Mercer et al., GeoTrans, Inc., Robert S. Kerr Environmental Research Laboratory, Ada, OK.
3. *CRC Handbook of Chemistry and Physics,* R. C. Weast and M. J. Astle, 62 nd ed., CRC Press, Boca Raton, FL., 1981.
4. Notes of telephone conversation between W. White (SWEC) and R. Elliott (Hill AFB) on 3/1/94 and 3/8/94.
5. Response to Stone & Webster letter (2/16/94) by R. Elliott received on 3/7/94.
6. Fax from Greg Smith, Great Lakes Environmental Center, to Roger Long, SWEC, dated 5/5/94.

ANALYSIS PREPARATION

This analysis was prepared by:

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Denver, Colorado 80217-5406
Contact: Dr. Richard Carmichael 303-741-7169

REVIEW

Project Manager
This analysis accurately reflects the performance and costs of this remediation

x [signature]

William R. James, PhD, P.E.
Remedial Project Manager
Hill Air Force Base

Soil Vapor Extraction and Bioventing for Remediation of a JP-4 Fuel Spill at Site 914 Hill Air Force Base, Ogden, Utah

Case Study Abstract

Soil Vapor Extraction and Bioventing for Remediation of a JP-4 Fuel Spill at Site 914, Hill Air Force Base, Ogden, Utah

Site Name:
Hill Air Force Base, Site 914

Location:
Ogden, Utah

Vendor:
Not Available

SIC Code:
9711 (National Security)

Waste Source:
Spill of JP-4 Jet Fuel

Purpose/Significance of Application:
One of the early applications involving sequential use of SVE and bioventing technology.

Contaminants:
Total Petroleum Hydrocarbons (TPH)
- TPH concentrations in untreated soil ranged from <20 to 10,200 mg/kg with average soil TPH concentration of 411 mg/kg

Technology: Bioventing Preceded by SVE

Bioventing
- 4 vent wells (Numbers 12-15) located on the southern perimeter of the spill area; 31 monitoring wells; 3 neutron access probes (for soil moisture monitoring)
- Vent wells approximately 50 feet deep with 4-inch diameter PVC casings, screened from 10 to 50 feet below ground surface
- Monitoring wells - ranged in depth from 6 to 55 feet with 1-inch diameter PVC casings, screened from 10 to 50 feet below ground surface
- No treatment of extracted vapors required (hydrocarbon concentrations <50 mg/L; use of catalytic incinerator not required)
- Air flow - 250 acfm
- Soil moisture - 6 to 12%
- Nutrients added - C:N:P ratio of 100:10:10

SVE
- 7 vent wells (Numbers 5-11 located in areas of highest contamination), 31 monitoring wells, 3 neutron access probes (soil moisture monitoring)
- Vent wells approximately 50 feet deep with 4-inch diameter PVC casings, screened from 10 to 50 feet below ground surface
- Plastic liner installed over part of spill area surface to prevent local air infiltration and bypassing of air flow to the vent well directly from the surface
- Monitoring wells - range in depth from 6 to 55 feet with 1-inch diameter PVC casing and a 2-foot screened interval to the bottom of the well
- Catalytic incinerator for extracted vapor
- Air flow - 1,500 acfm (maximum), 700 acfm (typical)

Period of Operation:
October 1988 - December 1990

Cleanup Type:
Full-scale cleanup

Cleanup Authority:
State: Utah

Point of Contact:
Robert Elliot
OO-ACC/EMR
7274 Wardleigh Road
Hill AFB, Utah 84055

Soil Vapor Extraction and Bioventing for Remediation of a JP-4 Fuel Spill at Site 914, Hill Air Force Base, Ogden, Utah (Continued)

Type/Quantity of Media Treated:
Soil
- 5,000 yds^3 contaminated by spill (surface area of 13,500 ft^2)
- Approximate extent of 10,000 mg/kg JP-4 contour covered area 100 by 150 feet
- Formation consists of mixed sands and gravels with occasional clay lenses
- Air permeability ranged from 4.7 to 7.8 darcies

Regulatory Requirements/Cleanup Goals:
- 38.1 mg/kg TPH
- Cleanup conducted under Utah Department of Health's "Guidelines for Estimating Numeric Cleanup Levels for Petroleum-Contaminated Soil at Underground Storage Tank Release Sites"

Results:
- Achieved specified TPH levels
- Average TPH soil concentrations in treated soil reduced to less than 6 mg/kg;
- 211,000 lbs of TPH removed in approximately 2 years of operation;
- Removal rate ranged from 20 to 400 lbs/day

Cost Factors:
- Total costs of $599,000, including capital and 2 years of operating costs
- Capital costs - $335,000 (including construction of piping and wells, other equipment, and startup costs)
- Annual operating costs - $132,000 (including electricity, fuel, labor, laboratory charges, and lease of equipment for 2 year operation)

Description:
In January 1985, an estimated 27,000 gallons of JP-4 jet fuel were spilled at the Hill Air Force Base Site 914 when an automatic overflow device failed. Concentrations of total petroleum hydrocarbons (TPH) in the soil ranged from <20 mg/kg to over 10,000 mg/kg, with an average concentration of about 400 mg/kg. The spill area covered approximately 13,500 ft^2.

The remediation of this spill area was conducted from October 1988 to December 1990 in two phases: the soil vapor extraction (SVE) phase followed by the bioventing phase. The SVE system included 7 vent wells (Numbers 5-11) located in the areas of highest contamination, 31 monitoring wells, and a catalytic incinerator. The typical air flow rate through the vent wells was 700 acfm, with a maximum of 1,500 acfm. In addition, a plastic liner was installed over part of the spill area surface to prevent local air infiltration and bypassing of air flow to the vent well directly from the surface. Within a year, the SVE system removed hydrocarbons from the soil to levels ranging from 33 to 101 mg/kg. Further reduction of the hydrocarbon concentration in the soil, to levels below the specified TPH limit, was achieved by using bioventing for 15 months. The bioventing system included 4 vent wells (Numbers 12-15), located on the southern perimeter of the spill area, and the monitoring wells used for SVE system. Because hydrocarbon concentrations were <50 mg/L in the extracted vapors, the catalytic incinerator was not required for this phase. Biodegradation was enhanced by injecting oxygen, moisture, and nutrients to the soil. Average TPH concentrations in the treated soil were less than 6 mg/kg.

The total capital cost for this application was $335,000 and the total annual operating costs were $132,000. In monitoring biodegradation rates, oxygen depletion was found to be a more accurate estimator of biodegradation rate than carbon dioxide formation. Carbon dioxide sinks, such as biomass, solubility in water, and reaction with the soil, limited the usefulness of carbon dioxide formation as a process control parameter.

TECHNOLOGY APPLICATION ANALYSIS

SITE

Operable Unit: Hill Air Force Base, area around Building 914 as shown on Figure 1.
City, State: Ten miles south of Ogden, Utah

TECHNOLOGY APPLICATION

This analysis addresses field application of soil vapor extraction (SVE) as well as field and bench scale application of bioventing. The two methods were used sequentially at the site.

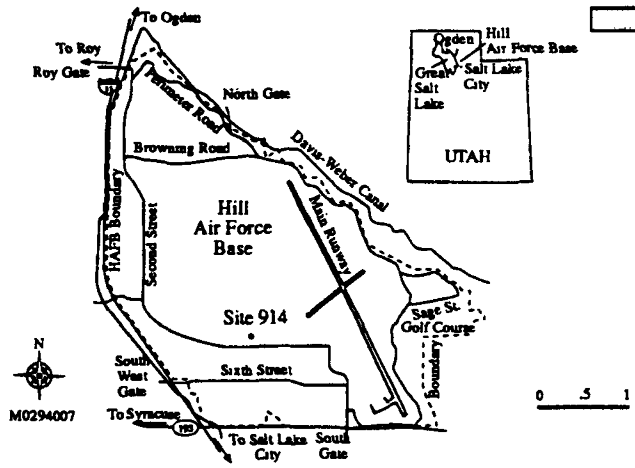


Figure 1. Location of Hill AFB, Utah and Site of JP-4 Fuel Spill (914 Site).

SITE CHARACTERISTICS

Site History/Release Characteristics

- Hill Air Force Base has been in operation since 1942, and Building 914 since 1972.
- In January 1985 27,000 gallons (estimated) of JP-4 jet fuel were released when an automatic overflow device failed. 2000 gallons were recovered as free product.
- The spill had an initial extent (Figure 2) of approximately 13,500 ft^2.
- No other fuel releases are documented; however, others are suspected to have occurred.
- Site remediation began in December 18, 1988.

Contaminants of Concern

- Specific contaminants of greatest concern in the unsaturated zone were: benzene, toluene, xylene, and ethylbenzene (BTEX). However, total petroleum hydrocarbon (TPH) concentration was more frequently monitored throughout the remediation due to relative ease of analysis compared to the specific compounds.
- Groundwater contamination was not an immediate concern because the groundwater is present only in discontinuous perched zones.
- No other specific compounds occurring in the original spill were identified.

Contaminant Properties

Properties of contaminants focused upon during remediation are provided below.

Property	Units	Benzene	Ethylbenzene	Toluene	Xylenes*
Empirical Formula		C_6H_6	C_8H_{10}	C_7H_8	C_8H_{10}
Density @ 20°C	g/cm^3	0.88	0.87	0.87	0.87 (avg)
Melting Point	°C	5.5	-95	-95	-47.9 to13.3
Vapor Pressure (25°C)	mm Hg	96	10	31	9
Henry's Law Constant	(atm)(m^3)/mol	5.59 X 10^{-3}	6.43 X 10^{-3}	6.37 X 10^{-3}	7.04X 10^{-3}
Water Solubility	mg/l	1,750	152	535	198
Octanol-Water Partition Coefficient;	Kow	132	1410	537	1830
Organic Carbon Partition Coefficient; Koc	ml/g	83	1,100	300	240
Ionization Potential	ev	9.24	8.76	8.5	8.56
Molecular Weight		78.12	106.18	92.15	106.18

*All 3 isomers (M, O, & P)

Nature & Extent of Contamination

Remedial investigation field activities at the site provided TPH concentrations as shown in Figures 2 and 3 and as described below.

- In January 1985, approximately 27,000 gallons of JD-4 jet fuel were accidentally released, of which about 2,000 gallons were recovered as free product.
- It was estimated that 5000 cubic yards of soil were contaminated by the spill.
- Soil samples were taken at each vent well location at five foot depth intervals down to 66 feet (see Figure 2).
- Soil concentrations were found to vary from <20 to 10,200 mg TPH per kg soil with an average of 411 (as of 10/88).
- Nine of the soil samples were analyzed for concentration of benzene, toluene and xylene. The benzene concentration was <20 mg/kg for all samples. The toluene concentration ranged from <20 to 308 mg/kg. The xylene concentration ranged from <20 to 600 mg/kg.

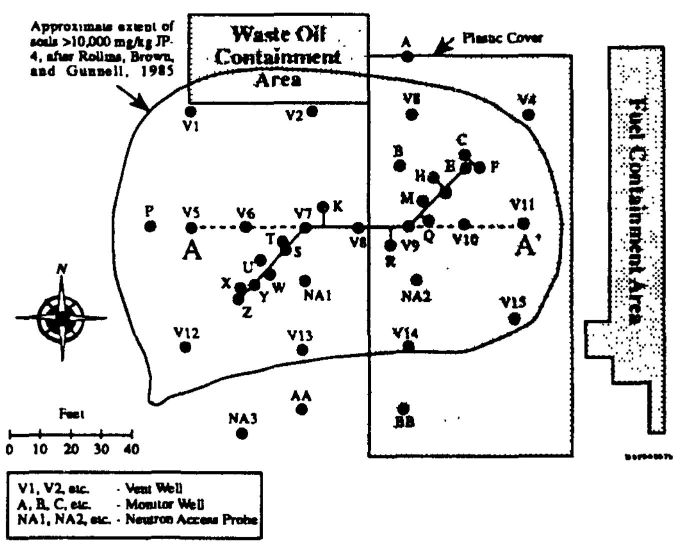
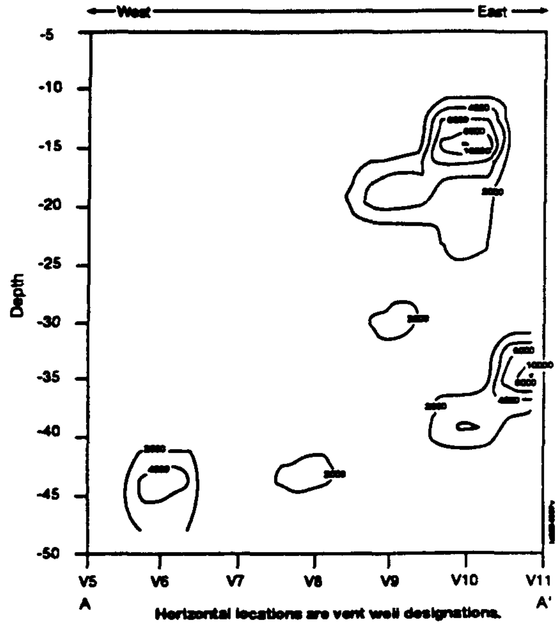


Figure 2. Hill AFB, Utah, Site Map Illustrating the Locations of Vent Wells and Monitoring Ports.

Contaminant Locations and Geologic Profiles

Figure 3. Vertical Isoconcentration View of Sampled Total Petroleum Hydrocarbon Concentration (mg/kg of soil) as a Function of Depth (ft.) Prior to soil Venting (10/88).



Hydrogeologic Units

- The spill is contained in the Provo formation, which is a delta outwash of the Weber River.
- The formation consists of mixed sands and gravels with occasional clay lenses.
- The formation extends to a depth of approximately 50 feet and is then underlain by a 200 to 300 foot thick clay layer.
- Areas of high TPH soil concentration appear to correlate with the presence of clay lenses.

Site Conditions

- Hill AFB elevation ranges from 5010 to 4570. The elevation in the vicinity of the spill is 4760 feet.
- The area has an arid climate with average ambient temperature of 58°F. The average minimum is 22°F, and the average high is 85°F.
- Precipitation averages 20.1 inches per year. With a maximum monthly precipitation of 6.4 inches occurring in May.
- The direction of groundwater flow at the site is from the east to the west.

Key Soil or Key Aquifer Characteristics

Property	Units	Range or value
Porosity	%	30 to 50
Particle density	g/cm^3	0.3 to 0.5
Soil bulk density	g/cm^3	0.37 to 0.48
Particle diameter	mm	0.8 to 10
Soil organic content	%	0.08 to 0.86
Moisture content	%	1.4 to 18% with average of <6%
Permeability	cm^2	10^{-12} to 10^{-10}
Hydraulic conductivity	cm/s	10^{-12} to 10^{-10}
Air conductivity	darcy	4.7 to 7.8
Depth to groundwater	ft	variable due to arid conditions, approximately 50 ft.
Groundwater temperature	°C	10 to 12
Groundwater pH @ 25°C		7.2 to 7.5
Aquifer thickness	ft	10 to 15

TREATMENT SYSTEM

- Both soil vapor extraction (SVE) and bioventing were used at this site. Bioventing is still active.
- Both soil vapor extraction and bioventing use forced air flow through the contaminated formation. However, each method is used for a different purpose and is optimized for different operating conditions.
- SVE normally uses significantly higher air flow rates than does bioventing. The higher air flow acts to strip the hydrocarbons, transferring them from the soil to the gas phase.
- Soil vapor extraction is more applicable to treating high concentrations of volatile hydrocarbons.
- SVE will remove hydrocarbons from the pore space thereby preparing the soil for bioremediation. Some bioremediation also occurs during SVE.
- With bioventing, air flow aerates the soil to promote biological conversion of the hydrocarbon to biomass, CO_2 and H_2O. The CO_2 and the H_2O are removed in the gas phase. Bioventing can be used to treat less volatile hydrocarbons.

Overall Process Schematic

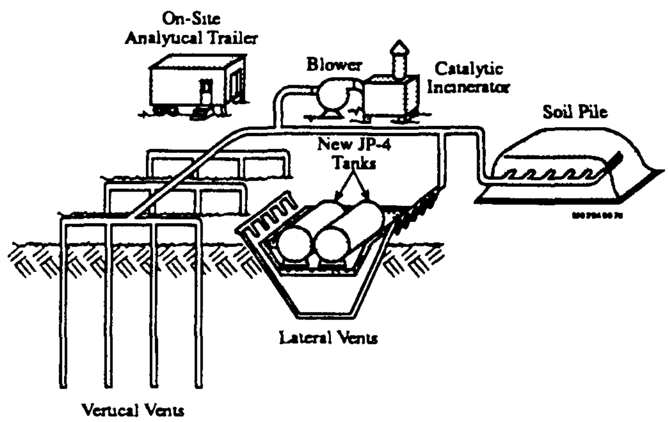


Figure 4. Conceptual drawing of the Hill AFB, Utah, Field Soil Venting Site.

System Description

- The treatment system as shown in Figures 2 and 4 and as described below consists of 15 vent wells, 31 monitor wells and 3 neutron access probes. The system also uses a single background vent well, which is not shown on the figures.
- Vent wells allow for soil gas to be actively removed from the formation. The monitor wells are used to analyze *in situ* soil gas composition and measure vacuum efficiency. The neutron access probes extend to a depth of 50 feet and are used to monitor soil moisture.
- The background vent well is similar in design and operation to the other vent wells but is located 700 feet north of the spill site and is used to establish baseline soil gas conditions in the uncontaminated formation. A separate blower was used with the background vent well.
- A plastic liner was installed over part of the spill area surface to prevent local air infiltration and bypassing of air flow to the vent well directly from the surface.
- Additional equipment shown in Figure 4 includes the blower (two in parallel), catalytic incinerator, and associated manifold piping.

System Operation

Soil Vapor Extraction Phase

- The blower suction is connected via the manifold piping to vent wells 5 through 11 which are located in the contaminated formation.
- Air flow is induced from the ground surface, through the contaminated formation, into the vent manifold, to the blower and finally discharged through the catalytic incinerator.
- A plastic lining restricts air flow directly from the surface to the vent wells, requiring the air flow into a longer path laterally across the formation to the vent wells
- The catalytic incinerator is used to destroy hydrocarbon gasses that are vented from the formation.

Bioventing Phase

- After it was determined that the soil vapor extraction was no longer efficient for removing hydrocarbons from the formation, the bioventing phase was initiated by changing the blower suction manifold to wells 12 through 15, on the periphery of the contaminated formation.
- Soil gas was drawn from the wells (with additional soil gas being drawn from a soil pile remediation project) at a reduced flow rate. At this flow rate, the total hydrocarbon concentration was reduced to below 50 mg/l. The incinerator, therefore, was not required and was permanently removed from service.

Well Design Close-Up

The vent wells are all approximately 50 feet deep. They all have 4 inch diameter PVC casing and a screened interval of 40 feet. The screened interval begins approximately 10 feet below ground surface The depth of the monitor wells varies from 6 to 55 feet. They all have 1 inch diameter PVC casing and a 2 foot screened interval at the bottom of the well. The details of the well design are shown in Figure 5. The following table gives the depth at the bottom of each monitor well designated in Figure 2.

Well	Depth (ft)	Well	Depth (ft)	Well	Depth (ft)
A	30	M	25	W	25
B	6	N	48	X	6
C	40	P	30	Y	55
E	25	Q	30	Z	25
F	25	R	30	AA	30
H	46	S	6	BB	30
J	30	T	55		
K	25	U	6		

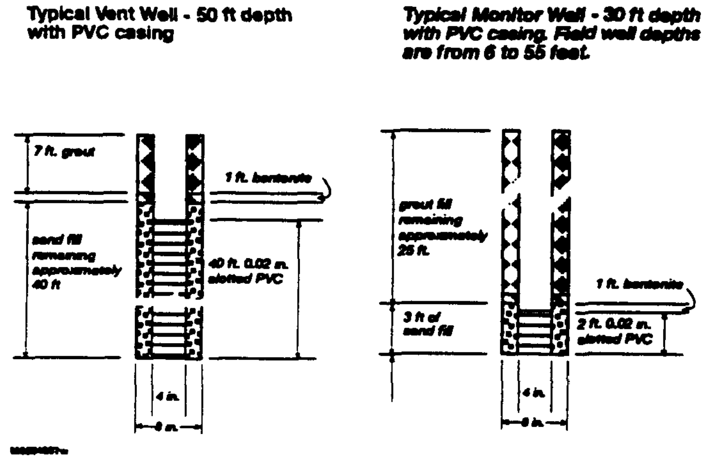


Figure 5 - Typical Well Design

Key Design Criteria

No specific design criteria were established in the document. However, for SVE key design criteria would include the following:

- vacuum pressure in the wells
- air flow rate through the vent wells
- air temperature in the wells
- hydrocarbon composition in the vent gas

For bioventing operations, key design criteria would include:

- soil moisture content
- soil gas oxygen concentration at monitor wells
- soil nutrient concentration
- hydrocarbon composition in the soil

Key Monitored Operating Parameters

SVE parameters monitored

- Total blower flow rate in acfm (actual cubic feet per minute - continuous measurement).
- Air flow Rate for a set of wells (continuous measurement).
- Offgas percent oxygen (continuous measurement).
- Offgas percent carbon dioxide (continuous measurement).
- C13/C12 isotope ratio (intermittent measurement).

Bioventing parameters monitored

- Soil Moisture content (intermittent measurement).
- Soil TPH content (intermittent measurement).
- Soil vapor Hydrocarbon concentration (intermittent measurement).
- *In situ* soil vapor percent oxygen content (continuous measurement).
- *In situ* soil vapor percent carbon dioxide (continuous measurement).

PERFORMANCE

Performance Objectives

- Remediate the site so that soil TPH is within the limit set by the Utah Department of Health (38.1 mg/kg).
- Determine the affect of SVE at the site.
- Determine the affect of bioventing at the site.
- Conduct a bioventing/soil venting study that will generate sufficient data to demonstrate effectiveness and provide support for designs at other similar sites.

Treatment Plan

Initial Phase

- Determine the extent of site TPH contamination by taking soil samples in the wells at five foot depth intervals. The TPH concentration is determined by gas chromatography. A plot of this data is given in Figure 3.

Soil Vapor Extraction Phase (bioventing is not optimized during this phase)

- Perform SVE with a maximum 1500 acfm (700 acfm is typical) flow for the site. Vent gas is collected through vent wells 5-11, which are located in the areas of highest contamination. The system operation is 24 hours per day.
- Measure effectiveness of SVE by monitoring the air flow rate and the exit soil gas concentration. (This data was not presented in the report).
- Measure the effectiveness of bioventing by continuously monitoring the concentration of soil gas O_2 and CO_2. If a typical hydrocarbon composition is assumed, the amount of hydrocarbon degraded can be calculated by comparing either the rise in CO_2 or the decrease in O_2 relative to the background concentrations. This method should give a conservative estimate since hydrocarbon converted to biomass or partially degraded to another organic compound is not accounted for.
- Cease venting operations at three points in time and allow for "natural" biodegradation to occur. Measure the effective respiration as depletion of soil O_2 concentration. This allows for determination of the rate of reaction (biodegradation) and the associated rate constant.
- Qualitatively analyze the CO_2 which occurs in the soil gas. Use the C13 / C12 isotope ratio to determine the origin of the carbon in the CO_2. The testing should be able to differentiate CO_2 which is from the atmosphere, hydrocarbon-based, and derived from carbonate rock .

Interim Phase

- Determine the extent of site TPH contamination by taking soil samples near the wells at five foot depth intervals. The TPH concentration is determined by gas chromatography. Note, this data set is not as complete as the initial data set. No plot is provided.

Bioventing Phase (bioventing is optimized during this phase)

- Reduce the air flow rate from 1500 acfm to 250 acfm. Redirect the air flow so that vent wells on the perimeter of the of the site are used for vapor extraction. These steps increase the residence time for biodegradation. Also, soil moisture is removed at a slower rate at the reduced air flow. The system operation is 24 hours per day.
- Add water to the spill site surface to increase the soil moisture level to between 6 and 12%.
- Add nutrients, such as phosphates, nitrates, and ammonia, with water to the spill site. The nutrients were added in a C:N:P ratio of 100:10:10 based on the soil TPH analysis taken in 9/89.
- Perform *in situ* respiration tests to determine the effectiveness of the steps to promote biodegradation. Soil gas O_2 monitoring was used to calculate the mass of hydrocarbon degraded in this phase.

Final Phase

- Determine the extent of site TPH contamination by taking soil samples in the wells at five foot depth intervals. The TPH concentration is determined by gas chromatography.

Results

- Figures 6 and 7 show the results of three successive respiration tests at monitor wells M and Y, respectively. Oxygen is consumed at a reduced rate at monitor well Y over the course of the respiration tests. The final test shows virtually no oxygen depletion in the area. This indicates a low level of biological degradation occurring. The low rate of degradation may be due to reduced soil hydrocarbon (i.e. remediation is nearly complete) or to low levels of soil moisture. Soil moisture would tend to be depleted due to the relatively high air circulation rates established for SVE. At site M, the O_2 depletion rate (biodegradation rate) increases with successive respiration tests. This is a location below the plastic cover. The data indicates that remediation is not complete and that the area was formerly oxygen starved.
- Figures 8 and 9 show soil gas concentrations of O_2, CO_2, and hydrocarbon at the monitor well locations and the vent well locations after the conclusion of the third respiration test. The data show that high levels of O_2 correlate with low levels of hydrocarbon and CO_2. In general, a high level of oxygen with little carbon dioxide or hydrocarbon suggests that any JP-4 originally in the soil has been removed. Also, note that vent well hydrocarbon levels are all lower than the monitor well levels. This occurs because the 40 foot screen of the vent wells collects a composite sample of the soil gas in the vicinity. As a result, local areas of high concentration are diluted.

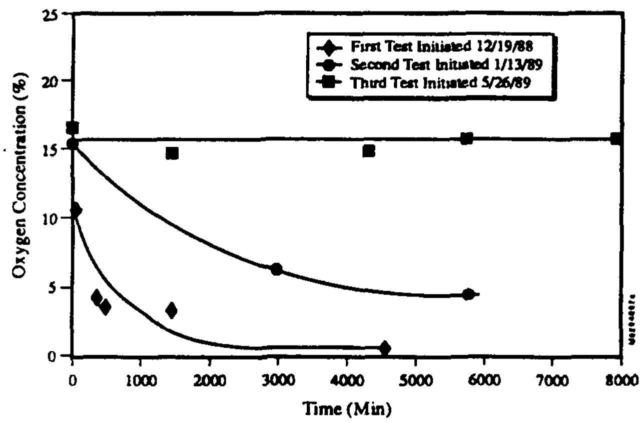


Figure 6. The Results of the Three Successive In Situ Respiration Test at Monitoring Point Y (65 feet below land surface), Hill AFB, Utah.

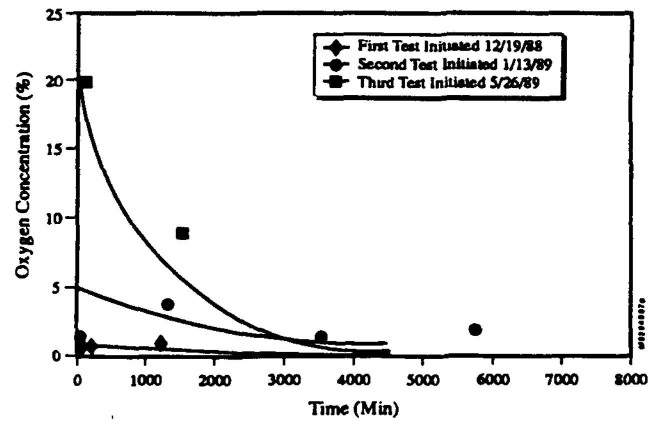


Figure 7. The Results of the Three Successive In Situ Respiration Test at Monitoring Point M (25 feet below land surface), Hill AFB, Utah.

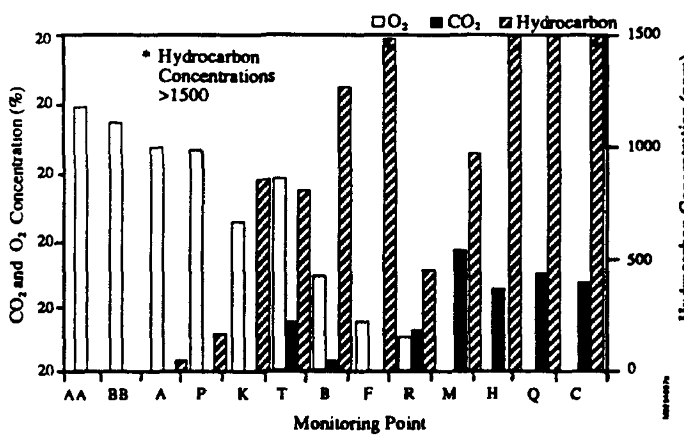


Figure 8. JP-4 Hydrocarbon (HC), O_2 and CO_2 Concentrations 9 June 1989 in the Monitoring Points at the Conclusion of the Third In Situ Respiration Test.

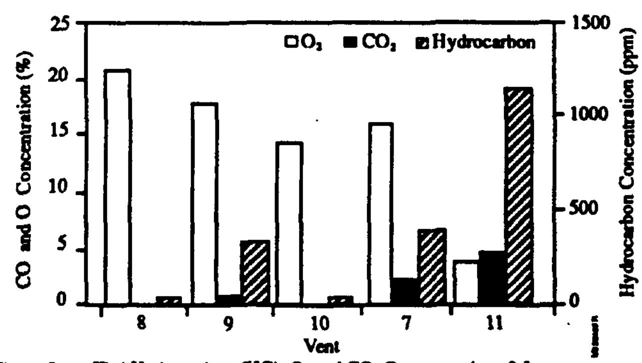


Figure 9. JP-4 Hydrocarbon (HC), O_2 and CO_2 Concentrations 9 June 1989 in the Vents at the Conclusion of the Third In Situ Respiration Test.

- The carbon isotope study is used to determine the origin of CO_2 in the soil gas. The possible sources include the atmosphere, degraded hydrocarbon, and decomposition of carbonate rock in the formation. The isotope ratio is characteristic of a given source of carbon. The laboratory analysis shows that vent gas CO_2 has an isotope ratio characteristic of petroleum and that less than 0.2% of the soil gas volume is due to CO_2 not derived from the JP-4.

Operational Performance

Volume of air circulated

The following table and figure show the air flow volumes and the affect on TPH removal.

As of Date	Total vented soil gas in 1000's of acf
12/18/88	0
12/19/88	42.5
1/13/89	540
4/1/89	8642
5/26/89	45,000
9/30/89	167,000
11/14/90	512,000

- *Figure 10 shows how the fraction of hydrocarbon removal due to bioventing has been affected by the changing air flow rates. In general, as the air flow rate is reduced, removal due to SVE decreases. The rate of biodegradation is unchanged, but the relative contribution of biodegradation increases.*

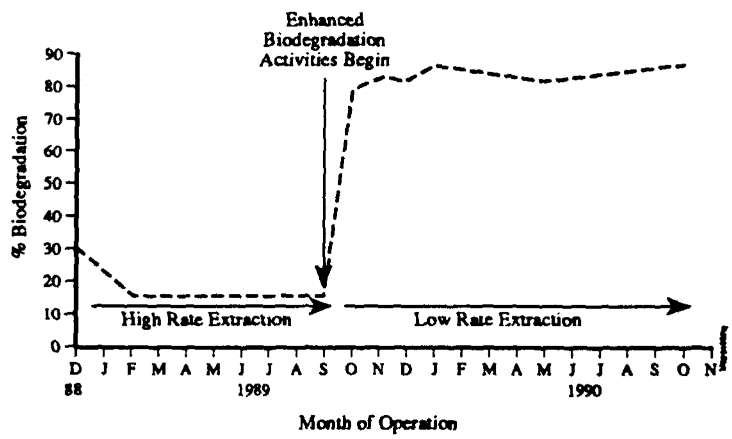


Figure 10. Percent of Recovered Hydrocarbon Attributed to Biodegradation Reactions at the Hill AFB, Utah, Soil Venting Site Based on Oxygen Consumption in the Vent Gas

Volume of water added

As of Date	Total gallons of water added to surface	Average water flow rate - gpm
5/28/90	0	—
9/21/90	1,000,000	30

Mass of nutrients added

- 300 lb of N as ammonium nitrate, 30 lb of P as treble superphosphate were added to the soil.
- Nutrients were added in three phases from 8/10/90 to 9/21/90. The nutrients were applied by direct surface addition, tilling of the first six inches of soil, and irrigation of the area.

System Downtime

SVE system was down for six days because the hydrocarbon vapor catalytic incinerator was out of service.

Treatment Performance

Total Pounds Contaminants Removed

As of Date	Cumulative lbs of TPH removed by vapor extraction	Cumulative lbs of TPH removed by bioventing	Cumulative lbs of TPH removed	Rate of TPH removal lb/day by vapor extraction
12/18/88	0	0	0	200-400
9/30/89	114,400	23,200	137,600	200-400
10/1/89	114,400	23,200	137,600	20
11/14/90	118,200	92,900	211,100	(not given)

- Figures 11 and 12 show the estimated cumulative hydrocarbon removal due to soil vapor extraction and bioventing as a function of time.

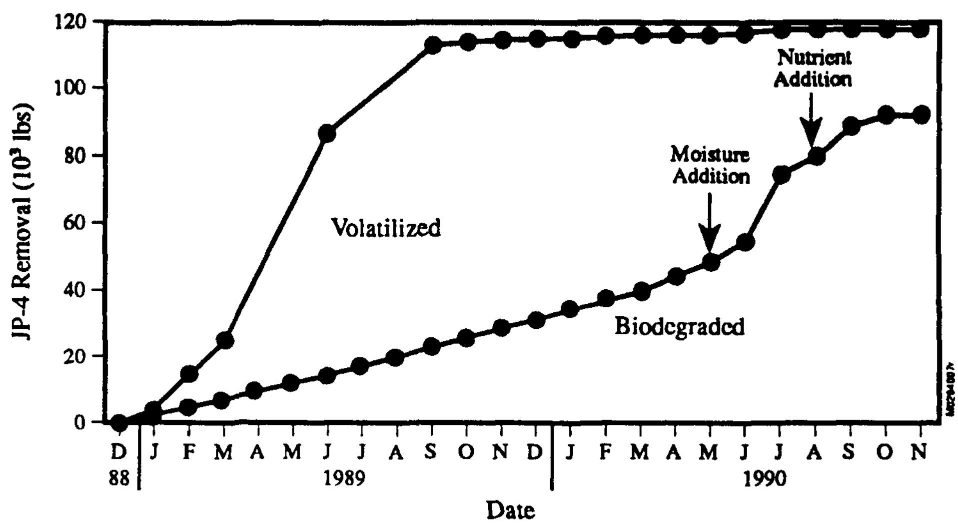


Figure 11. Cumulative Hydrocarbon Removal (Volatilized and Biodegraded) at Hill AFB, Utah, Soil Venting Site (from 18 December 1988 to 14 November, 1990)

Performance Assessment

- It is estimated that 211,000 lb of hydrocarbon were removed from the site as a result of SVE and bioventing. The original spill was estimated at 27,000 gallons. At the time of the spill, 2000 gallons of free liquid were recovered. If a specific gravity of 0.75 is assumed for the remaining hydrocarbon, the mass of the spill would be approximately 156,200 lbs. Despite the discrepancy in the estimates, the soil sampling at the end of the remediation showed that the site was sufficiently cleaned to meet the regulatory requirements.

- Figure 13 shows the average soil hydrocarbon concentrations at initial, intermediate and final phases of the site remediation.

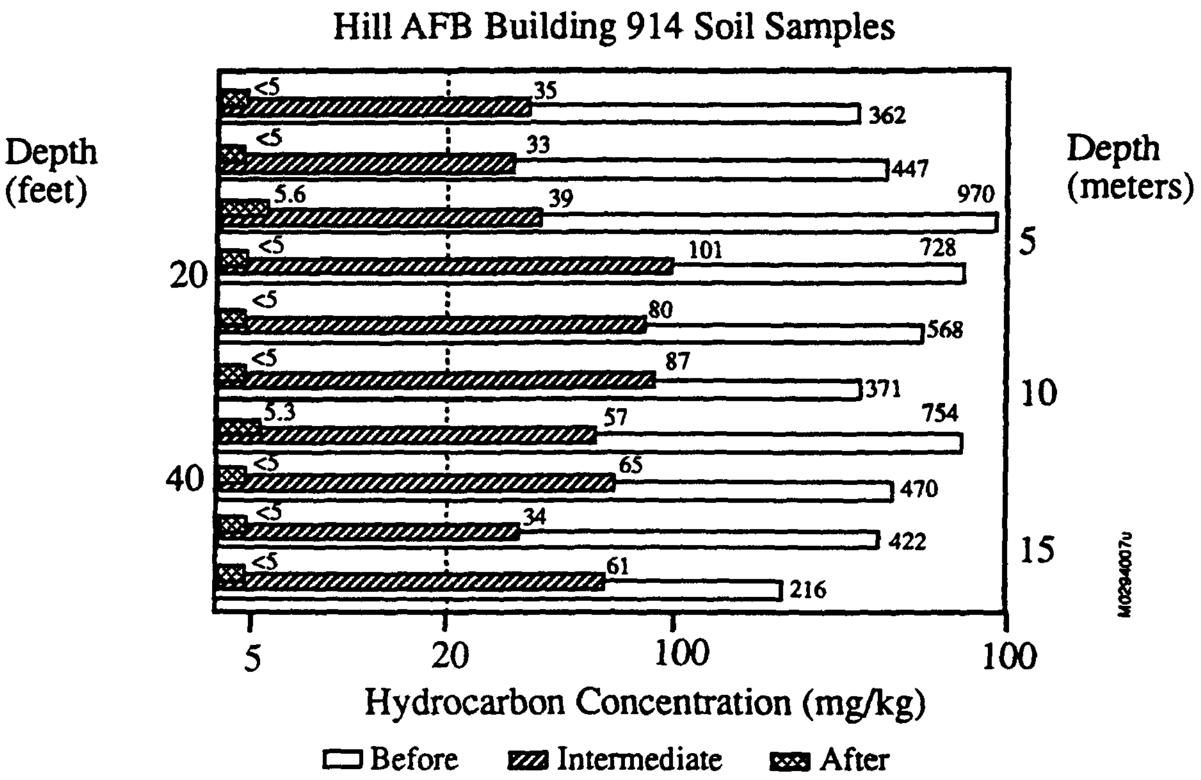


Figure 13. Mean Total Petroleum Hydrocarbon Concentrations at 5-Foot Intervals Prior to Venting (Before), After High RAte Operating Mode Venting but Before Low Flow Operating Mode with Moisture and Nutrient Addition (Intermediate), and After Low Flow Operating Mode with Moisture and Nutrient Addition (After).

- Following the demonstration, the state of Utah approved closure of the site.

COST

Capital Costs (thousands of dollars)

Construction of Piping System	$25
Construction of Wells	$130
Equipment Costs	$150
Startup Costs	$30
Total Capital Cost	$335

Annual Operating Costs (thousands of dollars)

Electricity (@ $0.07/kWhr)$	$13
Propane (@ $1.30/gal)	$24
Labor	$40
Laboratory Charges	$11
Maintenance Labor & Parts	$20
Lease of Incinerator	$24
Total Annual Operating Cost	$132

Cost Sensitivities (thousands of dollars)

Incinerator salvage value $10 (if originally purchased instead of leased)

REGULATORY / INSTITUTIONAL ISSUES

- The Davis County Health Department was involved in the planning stage of the SVE activities (1987).
- The site cleanup assessment was conducted subject to "Guidelines for Estimating Numeric Cleanup Levels for Petroleum-Contaminated Soil at underground Storage Tank Release Sites", which are criteria published by the Utah Department of Health.
- The recommended cleanup levels (RCL's) are presented for TPH, benzene, toluene, xylene, and ethylbenzene. These were derived from the above DOH guidelines by project personnel.
- The numerical levels are assigned based on the source of the spill (gasoline, diesel, or waste oil) and the environmental sensitivity of the area. The jet fuel has physical characteristics which lie between those for gasoline and diesel fuel. The RCL's are derived from the criteria for these listed fuels.
- Three levels of sensitivity are established based on the susceptibility of the groundwater to contamination from the spill leachate. Because of uncertainty in the ranking criteria, RCL's for Level I sensitivity (the lowest set of values) were used to assess the site cleanup.
- During combined SVE and bioventing operations, the catalytic incinerator was removed from service permanently once system modifications were made that reduced the soil vent gas hydrocarbon concentration below the permit limit of 50 mg/l.

Target Cleanup Levels/Criteria:

Contaminant	Level I RCL1 Soil mg/kg	Site maximum Soil mg/kg
TPH	65	38.1
Benzene	<0.2	<0.15
Toluene	<100	18
Xylene	<1000	2.5
Ethylbenzene	<70	<0.15

1. RCL's for specific aromatic compounds are for either gasoline or diesel releases. The RCL for JP-4 is midway between the value for gasoline and diesel.

SCHEDULE

Task	Start Date	End Date	Duration, months
Laboratory Studies	5/87	11/87	6
SVE Phase (ORNL)	10/88	9/30/89	12
Initial site soil analysis	10/88	—	—
First respiration test	12/19/88	12/22/88	—
Second respiration test	1/13/89	1/18/89	—
Third respiration test	5/26/89	6/9/89	—
Intermediate site soil analysis	10/89	—	—
Bioventing Phase (Battelle)	10/1/89	12/90	15
Nutrient addition tests	9/21/90	11/90	2
Final site soil analysis	12/90	—	—

LESSONS LEARNED

Key Operating Parameters

- SVE is preferable if the cleanup is required to proceed at a pace faster than that allowed by typical bioventing rates. However, provisions may be necessary for air emissions control.
- SVE is enhanced by high air flow rates and the presence of volatile hydrocarbons.
- Biodegradation is enhanced by adequate soil oxygen, moisture and nutrient level.
- Soil moisture appeared to have a greater impact than did nutrient level.

Implementation Considerations

- The system modifications required to decrease the soil gas hydrocarbon concentration below the permit limit included use of vent wells only at the periphery of the spill (areas of low soil TPH concentration) and reduced soil gas flow rates. These steps served to decrease the motive force for air stripping and increase the residence time for biodegradation.
- The above steps would enable direct venting to the atmosphere of the untreated soil gas, but the total time required to clean up the site would be increased.
- High air flow rates favor SVE but may retard biodegradation if too much soil moisture is removed or if contaminants do not have adequate residence time in the soil matrix.
- Contaminants (TPH) migrated in the formation over the course of the remediation activities. This was likely due to gravitational flow of the hydrocarbon, entrainment in seeping groundwater, or entrainment in the SVE air stream. Interim and final soil analysis should be sufficiently comprehensive to account for these possibilities.

Technology Limitations

- SVE is limited to hydrocarbons that are sufficiently volatile to allow air stripping.
- Bioventing is limited to hydrocarbons that can be degraded by the local bacteria. In addition, sufficient soil oxygen, moisture and nutrients are required.
- Estimates of biodegradation are more accurate if oxygen depletion rather than carbon dioxide formation is used. Various carbon dioxide sinks exist in the system. These would include biomass, solubility in water, and reaction with the soil. Oxygen is not as sensitive to these sinks.

Future Technology Selection Considerations

- The plastic cover did not result in significant air flow redirection at the spill site. This is probably because vent well screened intervals began at a depth of 10 feet and vertical hydraulic conductivity is lower than horizontal hydraulic conductivity at the site. Air distribution in the formation is in general an important parameter to address.
- Methods to optimize bioventing and SVE as a simultaneous process should be addressed in greater detail. However, at this site it was preferable to maximize bioventing (at the expense of SVE) in order to avoid air quality issues associated with the high vent gas flow rate.
- Soil chemistry criteria should be developed to establish when the application of nutrients would be beneficial to the bioventing process.

SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s 1, 2, 3 (from list below)
Treatment System:	Source #s 1,4,5
Performance:	Source #s 1,4,5
Cost:	Source #s 1,4,5
Regulatory/Institutional Issues:	Source #s 1;4,5
Schedule:	Source #s 1,4,5
Lessons Learned:	Source #s 1,4,5

Chronological List of Sources

1. *Final Report for Hill A.F.B. JP-4 Site (Building 914) Remediation*, Battelle, Hill Air Force Base, Utah, July, 1991.
2. *Basics of Pump-and-Treat Ground-Water Remediation Technology*, EPA-600/8-90/003, Mercer et al., GeoTrans, Inc., Robert S. Kerr Environmental Research Laboratory, Ada, OK.
3. *CRC Handbook of Chemistry and Physics*, R. C. Weast and M. J. Astle, 62 nd ed., CRC Press, Boca Raton, FL, 1981.
4. Notes of telephone conversation between W. White (SWEC) and R. Elliott (Hill AFB) on 3/1/94 and 3/8/94.
5. Response to Stone & Webster letter (2/16/94) by R. Elliott received on 3/7/94.

ANALYSIS PREPARATION

This analysis was prepared by:
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Contact: Dr. Richard Carmichael 303-741-7169

REVIEW

Project Manager

This analysis accurately reflects the
performance and costs of this remediation:

X Robert Elliott, P.E.

Mr. Robert Elliot
OO-ACC/EMR
7274 Wardleigh Road
Hill AFB, Utah 84055-5137

Underground Storage Tanks (USTs)
Bioventing Treatment at Lowry Air Force Base (AFB)
Denver, Colorado
(Interim Report)

Case Study Abstract

Underground Storage Tanks (USTs) Bioventing Treatment at Lowry Air Force Base (AFB), Denver, Colorado

Site Name:
Lowry Air Force Base

Location:
Denver, Colorado

Contaminants:
Total Petroleum Hydrocarbons (TPH)
- Total Recoverable Petroleum Hydrocarbons (TRPH) concentrations of 15 to 14,000 mg/kg were measured in soil samples below the area excavated for landfarming
- BTEX concentrations in soil samples were lower than cleanup criteria

Period of Operation:
Status - Ongoing
Report covers - 8/92 to 4/94

Cleanup Type:
Full-scale cleanup (interim results)

Vendor:
Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, CO 80290

SIC Code:
9711 (National Security)

Technology:
Bioventing
- 6 piping manifolds (each consisting of two 10 ft, 2 in diameter screens)
- Placed in excavation at right angles (in a horizontal plane), surrounded with 1 to 2 ft layer of pea gravel
- Aerated to maintain an oxygen concentration greater than 14%
- Carbon dioxide concentration maintained at less than 4%

Cleanup Authority:
State: Colorado

Point of Contact:
Lt. Tom Williams
3415 CES/DEV
Lowry AFB, CO 80230

Waste Source:
Underground Storage Tank

Purpose/Significance of Application:
Bioventing to remediate soils contaminated with heating oil which contained relatively high concentrations of TPH and relatively low concentrations of soluble contaminants (e.g., benzene).

Type/Quantity of Media Treated:
Soil
- No estimates have been made of the quantity of soil treated or hydrocarbon product degraded at the time of this report
- Moist, firm sandy clay in top 10-15 ft
- Medium to coarse-grained sand in next 15-80 ft

Regulatory Requirements/Cleanup Goals:
- Treated soil - TPH < 500 mg/kg; TRPH < 500 mg/kg; and BTEX < 100 mg/kg
- Cleanup conducted under EPA and State of Colorado Underground Storage Tank Regulations and the Colorado Department of Health's Remedial Action Category III (RAC III) action levels

Results:
- Bioventing project was not complete at time of this report
- No TRPH, BTEX, or TPH data are available at this time
- Bioventing system maintained adequate O_2 levels in the contaminated soil and removed CO_2 from the soil

Cost Factors:
- Final cost data were not available
- Total Capital Cost - $28,650 (including equipment, site work, engineering, project management)
- Annual Operating Costs - $32,875 per year (including electricity, maintenance, laboratory charges)

Underground Storage Tanks (USTs) Bioventing Treatment at Lowry Air Force Base (AFB), Denver, Colorado (Continued)

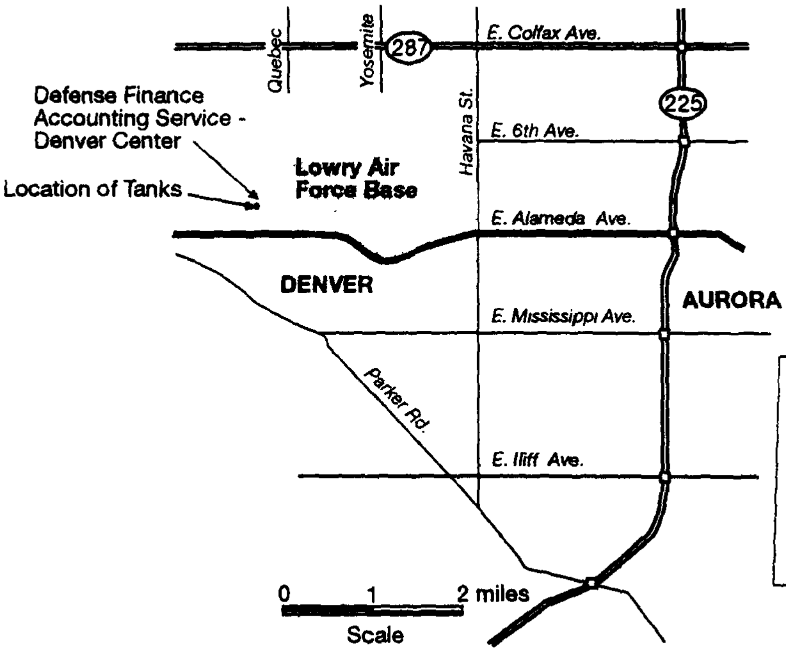
Description:
As a result of a leak of heating oil from an underground storage tank (UST) at Lowry Air Force Base in Denver, Colorado, soil was contaminated with total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylenes (BTEX). Following excavation of contaminated soil to a depth of 35 to 40 feet below ground level, soil sampling from the bottom of the excavation indicated that TRPH concentrations of 15 mg/kg to 14,000 mg/kg remained in the soils. A bioventing system, consisting of six bioventing piping manifolds, was installed at the bottom of the excavation and began operating in August 1992. The soil was aerated to maintain an oxygen concentration greater than 14% and a CO_2 concentration less than 4%.

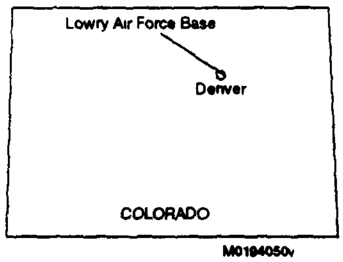
The bioventing of the contaminated soil at this site was ongoing as of April 1994. The target cleanup levels for the soil were TPH to less than 500 mg/kg; Total Recoverable Petroleum Hydrocarbons (TRPH) to less than 500 mg/kg; and BTEX to less than 100 mg/kg. The cleanup is being conducted under the authority of the Colorado Department of Health Underground Storage Tank Program. While no TPH, TRPH, or BTEX data were available at the time of this report, the bioventing system was found to have maintained adequate O_2 and CO_2 levels in the soil.

The total capital cost for this application is $28,650 and the estimated annual operating costs are $32,875. It was noted during this application that key operating parameters for bioventing are soil moisture, oxygen content, and carbon dioxide content; and that more frequent and better reported respiration test results would provide a more complete picture of the progress of the bioventing process, and indicate when final soil samples should be collected.

SITE

Figure 1





TECHNOLOGY APPLICATION

This analysis covers the use of bioventing to bioremediate soils contaminated with heating oil. The treatment began 5 August 1992 and is currently ongoing. This analysis covers performance through September 1993.

SITE CHARACTERISTICS

Site History/Release Characteristics

- The Defense Finance Accounting Service - Denver Center (DFAS-DE) is located on Lowry Air Force Base (AFB) at the east edge of the City of Denver, Colorado.
- This project was carried out in response to a suspected release of petroleum hydrocarbons (heating fuel oil) from an UST at the (DFAS-DE), adjacent to building 444.
- A suspected leak of 10,500 gallons of heating fuel oil was discovered by a discrepancy in inventory measurements during February 1992.
- Underground storage tank (UST) removal efforts commenced March 2, 1992, with uncovering of the suspected leaking UST, Tank 424. The soil above the tank was free of hydrocarbon odor.
- Leakage was confirmed by visual inspection of the removed tank on March 16, 1992.
- Initial notification of the release was provided in a letter dated April 7, 1992, to the CDH Underground Tank Program.

Contaminants of Concern

- Contaminants of greatest concern in the soil are BTEX (benzene, toluene, ethyl benzene, and xylenes), heating oil, and diesel fuel.

Contaminant Properties

Properties of contaminants focused upon during remediation are:

Property	Units	Benzene	Ethylbenzene	Toluene	Xylenes*
Empirical Formula		C_6H_6	C_8H_{10}	C_7H_8	C_8H_{10}
Density @ 20°C	g/cm^3	0.88	0.87	0.87	0.87
Vapor Pressure @ 20°C	mm Hg	100	10	36.7	10
Henry's Law Constant @ 25°C	(atm)(m^3) / mol	5.59×10^{-3}	6.43×10^{-3}	6.73×10^{-3}	7.04×10^{-3}
Water Solubility @ 20°C	mg/l	1,800	200	500	200
Log Octanol-Water Partition Coefficient; Log Kow		2.13	3.15	2.69	2.77-3.2
Site Specific Soil-Air Partition Coefficient; Kh /Kd	µg/l air / mg/kg soil		0.48	3.42	0.77
Organic Carbon Partition Coefficient; Koc	ml/g	83	1,100	300	240
Ionization Potential	ev	9.25	8.76	8.82	8.56
Molecular Weight		78.12	106.18	92.15	106.18

*All 3 isomers (M, O, & P)

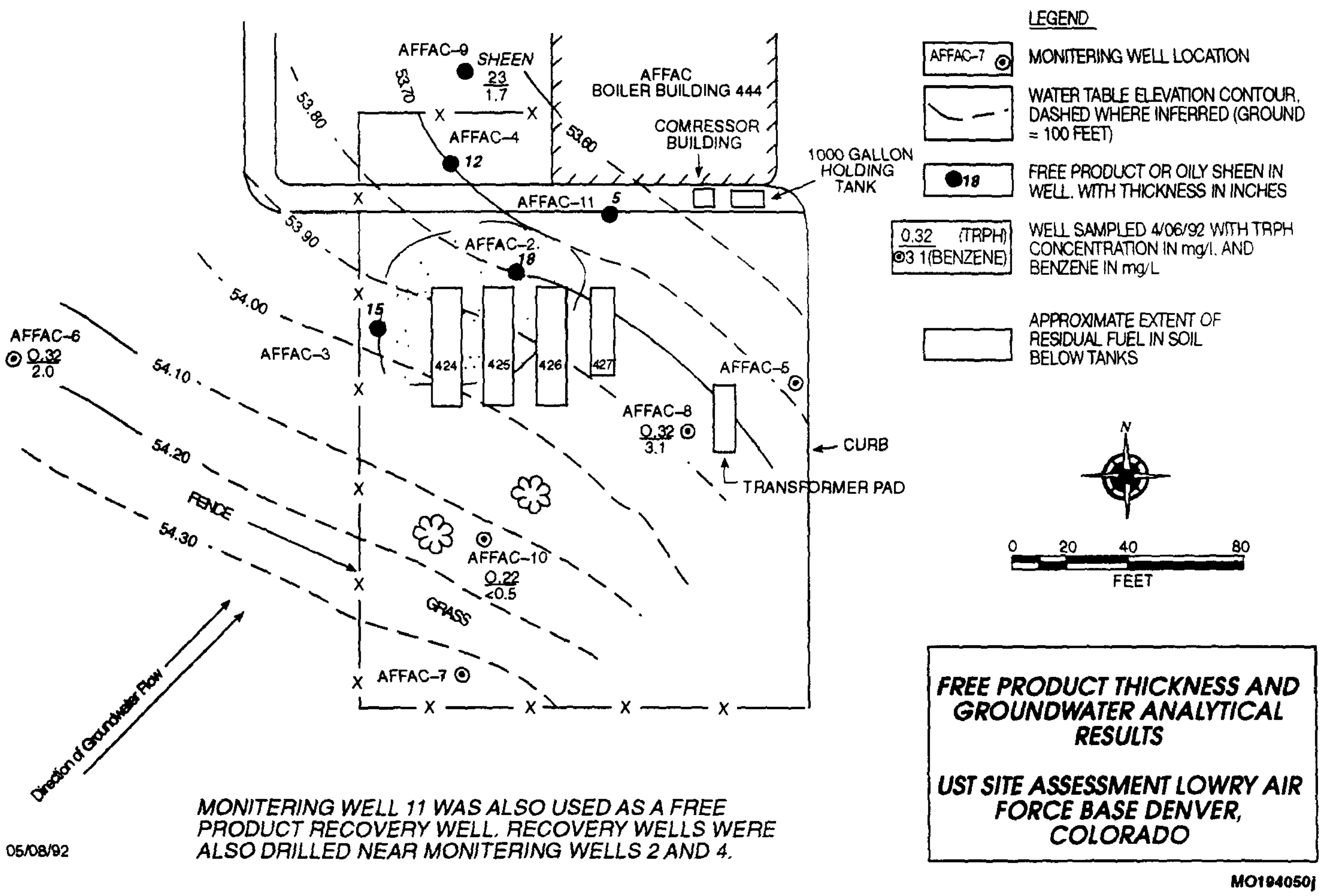
Nature & Extent of Contamination

- 4 USTs (Tanks 424, 425, 426 and 427) were removed.
- It was determined that only Tank 424 leaked.
- Components of the heating fuel oil did not significantly affect the groundwater. Heating fuel oil contains relatively low concentrations of soluble components (such as benzene) compared to lighter petroleum fractions such as gasoline. Groundwater treatment was not deemed necessary, but it was monitored during remediation activities.
- Groundwater benzene concentrations from 4 monitoring wells ranged from 1.7 to 3.1 µg/L. Concentrations of toluene, ethylbenzene, and xylenes were well below State standards and MCLs. Low TRPH concentrations (0.3 mg/L or less) were measured in 3 wells; 23 mg/L of TRPH was observed in the downgradient well.
- The soil was saturated with petroleum product immediately above the water table at 45 feet below ground surface. Residual fuel appeared to be confined with depth in some areas by a layer of finer-grained, dense sand encountered at 35 feet below the ground surface.

Contaminant Locations and Geologic Profiles

Remedial investigation field activities at the site have included:

Plume (Top View)



Hydrogeologic Units

- Thicknesses of unconsolidated alluvium >80 feet occur at the location of the DFAS-DE tanks.
- A layer of moist, firm sandy clay occupies the top 10 to 15 feet.
- The next 15 to 80 feet is a medium to coarse-grained sand.
- Aquifer is a water table aquifer.
- Groundwater gradient is roughly 0.4% to the northeast.

Site Conditions

- Elevation is about 5,390 feet.
- Average annual air temperature is 50°F. Diurnal temperature fluctuation averages 29°F. Record high 105°F; record low temperature -30°F.
- 14.81 inches precipitation/year; 58.3 inches of snow/year.
- 70% of possible sunshine.
- On the average, the first freeze is around October 12 and the last freeze is around May 5.
- Direction of groundwater flow is from the southwest to the northeast.

Key Soil or Key Aquifer Characteristics Measured

Property	Units	Range or value
Soil moisture content (landfarm)	%	6% to 11%
Hydraulic conductivity	cm/s	1.8 to 78.4 X 10^{-4}
Depth to groundwater	feet	45
Aquifer thickness	feet	>35
Depth to bedrock	feet	>80

Groundwater levels fluctuate seasonally from 1 to 4 feet in monitoring wells at this site.

TREATMENT SYSTEM

Three remediation technologies are being used to remediate this site. The three technologies selected complement each other and are not competitive, one with another

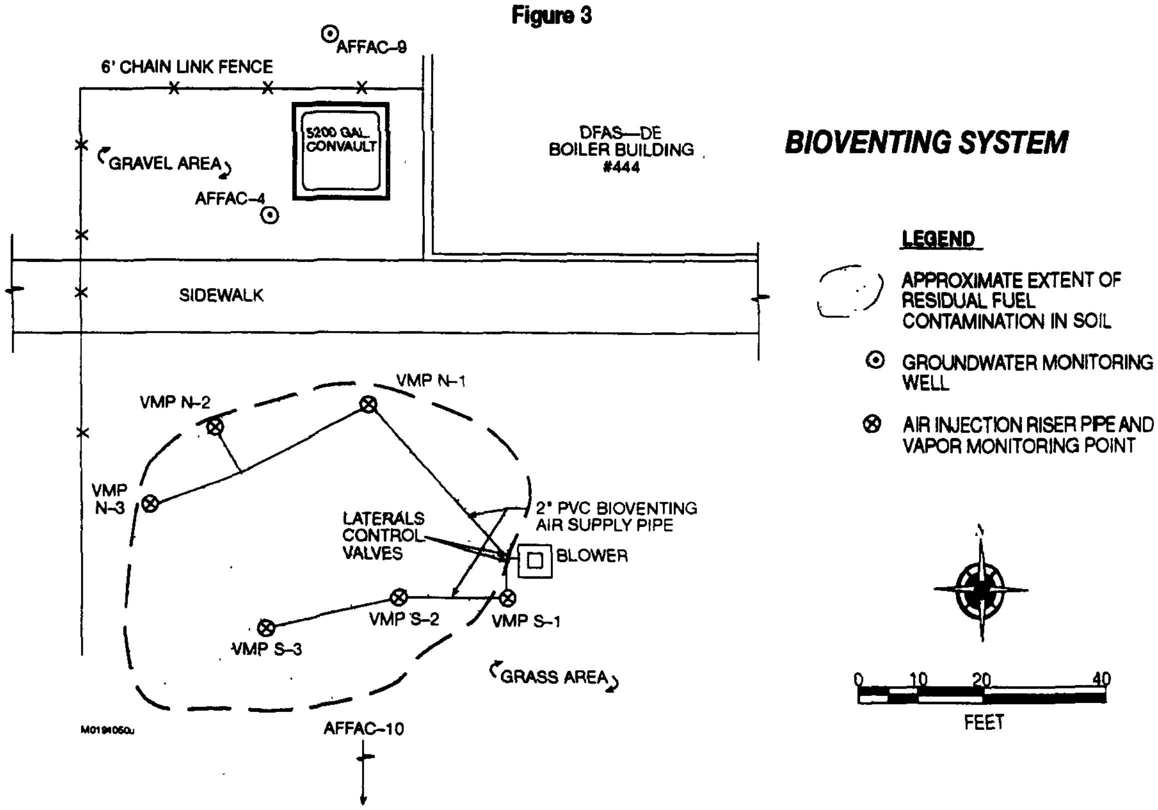
- Landfarming for the soil removed from the excavation.
- Bioventing for the soil remaining in the excavation.
- Product only pumping for the free product found floating on the water table.
- This report addresses bioventing only.

The Treatment System

- 5,400 cubic yards of petroleum contaminated soil was removed from the excavation. Soil that had indications of hydrocarbons present was excavated by a track hoe, hauled to a treatment location and is undergoing above ground biotreatment (landfarming).
- Soil was removed from below the tanks to a depth of 35 to 40 feet below ground surface.
- Soil sampling from the bottom of this excavation indicated that petroleum contamination remains below the excavation and above the water table in the northern part of the excavation. TRPH concentrations of 15 mg/kg to 14,000 mg/kg were measured in bottom soil samples. BTEX concentrations were less than RAC III criteria in all samples. The maximum concentrations of TRPH and BTEX were all observed at the 35 foot depth. The next highest concentrations were observed at the 40 foot depth. Limitations of the reach of excavation equipment and concerns with sidewall stability prevented the removal of contaminated soils at depths greater than 35 or 40 feet, because the groundwater was at 45 feet. As a result, 5 to 10 feet of residual contaminated soil was left in place.
- Before backfilling, 6 bioventing piping manifolds (each manifold consisting of two 10 foot long; 2" diameter polyvinyl chloride [PVC] screen) were installed at the bottom of the excavation in areas determined to contain residual contamination. The 10 foot manifold sections were placed in the excavation at right angles (in a horizontal plane). These screens were surrounded with a 1 to 2 foot thick layer of pea gravel. Each manifold connected to a 2" diameter PVC riser pipe that extended to the ground surface. These bioventing manifolds are aerating the remaining contaminated soil, thereby enhancing biodegradation of the residual fuel by naturally occurring soil microorganisms. The manifolds can also be used to introduce nutrients to the contaminated soils to enhance further biological fuel degradation rates.

Extent of Excavation

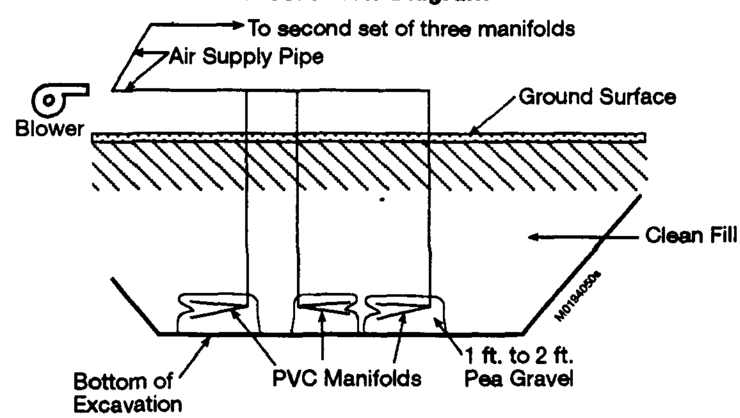
Figure 3



Overall Process Schematic

Figure 4

Process Flow Diagram



Key Monitored Operating Parameters

- Oxygen concentration is maintained at greater than 14%.
- Carbon dioxide is maintained at less than 4%.

PERFORMANCE

Performance Objectives

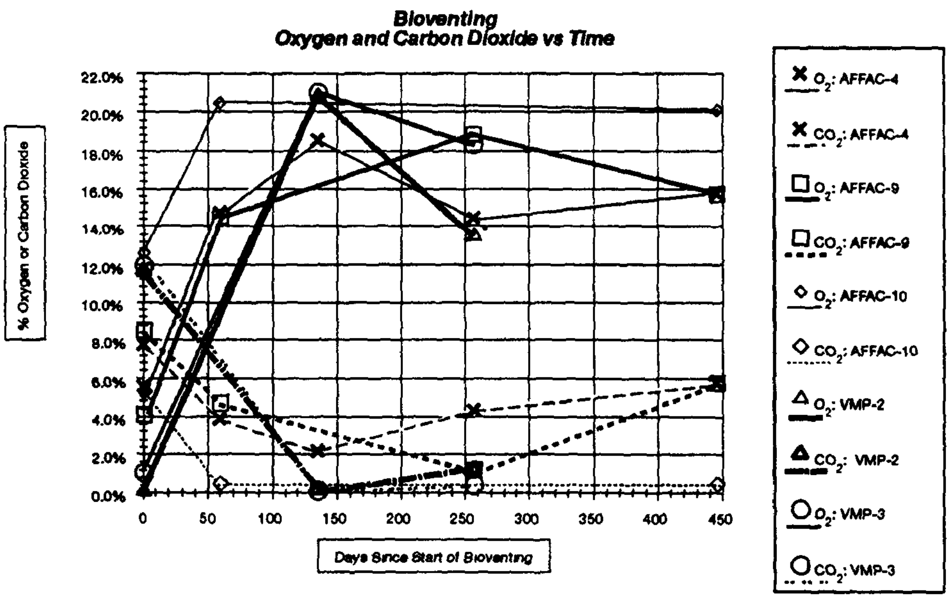
- There are no RODs or FFAs. However, compliance with EPA and State of Colorado UST regulations is required.
- The soil bioventing operations will be completed when composite soil samples indicate TRPH concentrations have been reduced to less than 500 mg/kg.

Treatment Plan

- If within the soil matrix the oxygen (O_2) level is low and the carbon dioxide (CO_2) level is high,it is assumed that microorganisms are degrading the hydrocarbons present. If biodegradation is occurring, then the process is limited by the depleted oxygen level. The microorganisms will consume the hydrocarbons at a high rate if the oxygen used by the microorganisms is replaced by bioventing.
- Wells will be installed and soil samples taken at some future time to confirm that the TRPH has been reduced to below 500 mg/kg.
- The cleaned soils will remain in place after soils bioventing treatment is completed.

Operational Performance

- The radius of oxygen influence created by the bioventing system exceeded the boundaries of soil contamination.
- Figure 5 shows the soil gas concentration of oxygen (O_2) and carbon dioxide (CO_2) at selected monitoring wells (AFFAC-n) and vapor monitoring points (VMP S-n). The data show that the O_2 initially (before treatment) was low, between 2% and 6%. At the same time the CO_2 was high, between 6% and 12%. After the bioventing system was placed in operation, O_2 levels increased and remained high, between 14% and 21%. During this same period, CO_2 levels decreased and remained low, between 0% and 6%. This indicates that lack of oxygen originally was limiting the biological destruction of the fuel oil hydrocarbons. Since bioventing commenced, adequate oxygen is available for bioremediation to take place.



See Figure 2 for the location of monitoring wells (AFFAC-n) and Figure 3 for the location of vapor monitoring points (VMP S-n).

- The bioventing system is effective in maintaining high O_2 levels in the contaminated soil left in place. The system also effectively removed CO_2 from the contaminated soils.

System Downtime

- The bioventing system was down for a short (unspecified) time because of a damaged supply pipe.

Treatment Performance

Total Pounds Contaminants Removed

- No estimates have been made of the quantity of soil treated or the quantity of hydrocarbon product destroyed.

COST

Capital Costs

Equipment	$2,700
Site Work	$3,700
Buildings/Structures	$900
Mechanical/Piping	$650
Electrical	$1,000
Subtotal	$8,950
Engineering	$5,000
Project Management	$2,200
Testing	$10,000
Cumulative Subtotal	$26,150
General & Administrative Overhead Costs @ 9.5%	$2,500
Total Capital Costs	$28,650
Annual Capital Cost (Over 2 years)	$14,325

Operating Costs (per year)

Electricity (@ $0.07/Kwhr)	$1,400
Laboratory Charges	$1,750
Maintenance Labor & Parts	$5,400
Monitoring	$10,000
Subtotal	$18,550
Total Annual Operating Cost	$32,875

REGULATORY/INSTITUTIONAL ISSUES

- The USTs were removed in conformance with American Petroleum Institute Recommended Practice 1604 and the National Fire Protection Association Code 30.
- The EPA and the State of Colorado review all documents produced by this project including the Quarterly Monitoring Reports. In addition, Lowry AFB personnel meet with the EPA and the State of Colorado once/month. Local communities are invited to the monthly environmental meetings.

Cleanup Criteria

- The Colorado Department of Health (CDH) Remedial Action Category III (RAC III) Action Levels are:

Compound	mg/kg
Total (Recoverable) Petroleum Hydrocarbons (TRPH)	500
Total Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX)	100

- The CDH's "Basic Standards for Ground Water" includes:

	µg/L
benzene	1
toluene	1,000
ethylbenzene	680
xylenes	none

- The MCL standard for benzene is 5 µg/L, the MCL for xylenes is 10,000 µg/L, but there is no MCL for TPH.
- Shallow groundwater beneath Lowry AFB is not being used as a drinking water supply and there is little or no likelihood that this will change.
- Target Cleanup Levels/Criteria:

Contaminant	mg/L
TPH	500

SCHEDULE

- There is no "originally planned schedule." Remediation will continue until the site meets the foregoing CDH regulatory requirements.
- As of May 1992, site restoration and assessment activities were completed by June 1992. Estimated time of completion was estimated to be 2 years.
- The bioventing system began operation August 5, 1992, and operates continuously.
- As of April 1994 treatment is not complete.

LESSONS LEARNED

Key Operating Parameters

- The key operating parameters are soil moisture, soil oxygen content and soil carbon dioxide content.
- More frequent and better reported respiration tests would provide a more complete picture of the progress of the soil remediation. It would also indicate when final soil samples should be obtained.

Implementation Considerations

- The time required for biotreatment is longer than other treatment methods such as incineration.
- Can be performed on site, reducing the need to excavate large quantities of soil.

Future Technology Selection Considerations

- Both landfarming (above ground bioventing) and *in situ* bioventing appear to have been successful at this site, but data is insufficient to make a judgment as to which process performed better.

SOURCES

Major Sources For Each Section

Site Characteristics:	1, 2, 6 and 7
Treatment System:	1 and 7
Performance:	1, 3, 4 and 5
Cost:	8
Regulatory/Institutional Issues:	1
Schedule:	1 and 8

Chronological List of Sources and Additional References

1. *Underground Storage Tanks Site Assessment Report and Corrective Action Plan,* Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., May 1992.
2. Underground Storage Tanks Site Assessment Report and Corrective Action Plan, Appendices, Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., June 1992.
3. *Quarterly Monitoring Report, Lowry Air Force Base,* Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., October 1992.
4. *Quarterly Monitoring Report-January 1993,* Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., January 1993.
5. *Quarterly Monitoring Report-November 1993,* Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., December 1993.
6. *RREL Treatability Data Base,* Version 4.0, EPA, November 15, 1991.
7. *Basics of Pump-and-Treat Ground-Water Remediation Technology,* EPA/600/8-90/003, Robert S. Kerr Environmental Research Laboratory, Ada, OK 74820, March, 1990.
8. *Personal Communication with Kent Friesen,* Engineering-Science, Inc., 1700 Broadway, Suite 900, Colorado 80290 (Phone, 303/ 831-8100).

ANALYSIS PREPARATION

This analysis was prepared by:
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REVIEW

Project Manager
This analysis accurately reflects the performance and costs of this remediation

X Tom Williams

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Underground Storage Tanks (USTs)
Land Treatment at Lowry Air Force Base (AFB)
Denver, Colorado
(Interim Report)

Case Study Abstract

Underground Storage Tanks (USTs) Land Treatment at Lowry Air Force Base (AFB), Denver, Colorado

Site Name:
Lowry Air Force Base

Location:
Denver, Colorado

Contaminants:
Benzene, toluene, ethylbenzene, and xylenes (BTEX) and Total Petroleum Hydrocarbons (TPH)
- Contaminated soil - BTEX < 100 mg/kg; Total Recoverable Petroleum Hydrocarbons (TRPH) up to 11,000 mg/kg; 3,100 mg/kg average
- Stockpiled soil - average TRPH of 3,983 mg/kg

Period of Operation:
Status - Ongoing
Report covers - 7/92 to 9/93

Cleanup Type:
Full-scale cleanup (interim results)

Vendor:
Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, CO 80290

SIC Code:
9711 (National Security)

Technology:
Land Treatment
- Soil spread on plastic sheeting to thickness of 14 to 18 inches
- One-time addition of ammonium nitrate nutrients (C:N:P ratios of 200:10:1)
- Soil aerated twice a month (April-November)
- Soil moisture content 10%-15%

Cleanup Authority:
State: Colorado

Point of Contact:
Lt. Tom Williams
3415 CES/DEV
Lowry AFB, CO 80230

Waste Source:
Underground Storage Tank

Purpose/Significance of Application:
Land treatment to remediate soils contaminated with heating oil which contained relatively high concentrations of TPH and relatively low concentrations of soluble contaminants (e.g., benzene).

Type/Quantity of Media Treated:
Soil
- Soil type firm sandy clay and medium to coarse-grained sand
- Soil moisture content ranged from 6% to 11%
- 5,400 yd^3 treated plus three additional truckloads of contaminated soil

Regulatory Requirements/Cleanup Goals:
- Treated soil - TPH < 500 mg/kg; TRPH < 500 mg/kg; and BTEX < 100 mg/kg
- Cleanup conducted under EPA and State of Colorado Underground Storage Tank Regulations and the Colorado Department of Health's Remedial Action Category III (RAC III) action levels

Results:
- Land treatment project was not complete at time of this report
- No TRPH, BTEX, or TPH data are available at this time
- Total Extractable Petroleum Hydrocarbon levels as of September 1993 ranged from 1,300-1,700 mg/kg

Cost Factors:
- Total Capital Cost - $104,257 (including site work, permitting, construction/mobilization/demobilization, pilot testing, project management); pilot testing was $76,000 of the total capital costs
- Estimated Annual Operating Costs - $18,460 per year (including laboratory charges, maintenance, monitoring)

Case Study Abstract

Underground Storage Tanks (USTs)
Land Treatment at Lowry Air Force Base (AFB)
Denver, Colorado (Continued)

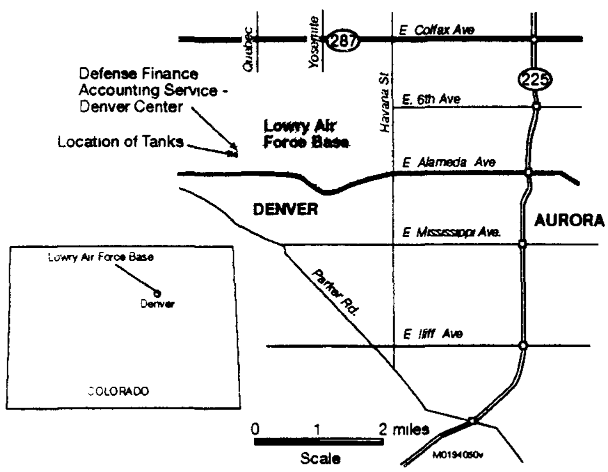
Description:
As a result of a leak of heating oil from an underground storage tank (UST) at Lowry Air Force Base in Denver, Colorado, soil at the site was contaminated with total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and xylenes (BTEX). An estimated 10,500 gallons of fuel oil were released. The USTs in the area were removed and the contaminated soil was excavated. Land treatment was selected for the excavated soil; treatment of about 5,400 cubic yards began in July 1992 and is ongoing at the time of this report. For this land treatment application, nutrients (ammonium nitrate) were added in a one-time application, the soil is tilled twice a month, and soil moisture content is kept between 10 to 15% by weight. The target cleanup levels for the soil are TPH to less than 500 mg/kg; Total Recoverable Petroleum Hydrocarbons (TRPH) to less than 500 mg/kg, and BTEX to less than 100 mg/kg. The cleanup is being conducted under the authority of the Colorado Department of Health Underground Storage Tank Program.

The estimated completion time for the land treatment operation was two years. However, as of September 1993, the treatment had not been completed. While no TPH, TRPH, or BTEX data were available at the time of this report, levels of Total Extractable Petroleum Hydrocarbons (TEPH) sampled as of September 1993 showed levels in the range of 1,300 to 1,700 mg/kg. These data and the results of a pilot test, which showed a general decrease in TEPH over time, appear to indicate that land treatment will be effective, though no projections for a completion date are available at this time.

The total capital cost for this project is $104,257 including $76,000 for pilot testing, and the estimated annual operating costs are $18,640. Available information to date indicates that the credibility of the land treatment soil assessment would have been improved if an adequate, random sampling program had been used for sample collection. In addition, laboratory analysis should have been consistent throughout the pilot test or an explanation of inconsistencies provided.

SITE

Figure 1



TECHNOLOGY APPLICATION

This analysis covers the use of landfarming to bioremediate soils contaminated with heating oil. The treatment began 1 July 1992 and is currently ongoing. This analysis covers performance through September 1993.

SITE CHARACTERISTICS

Site History/Release Characteristics

- The Defense Finance Accounting Service - Denver Center (DFAS-DE) is located on Lowry Air Force Base (AFB) at the east edge of the City of Denver, Colorado.
- This project was carried out in response to a suspected release of petroleum hydrocarbons (heating fuel oil) from an UST at the DFAS-DE adjacent to building 444.
- A suspected leak of 10,500 gallons of heating fuel oil was discovered by a discrepancy in inventory measurements during February 1992. In response to the suspected release, an emergency UST removal and site assessment project was performed.
- Underground storage tank (UST) removal efforts commenced March 2, 1992, with uncovering of the suspected leaking UST (Tank 424). The soil above the tank was free of hydrocarbon odor.
- Leakage was confirmed by visual inspection of the removed tank on March 16, 1992.
- Initial notification of the release was provided in a letter dated April 7, 1992, to the CDH Underground Tank Program.

Contaminants of Concern

- Contaminants of greatest concern in the soil are BTEX (benzene, toluene, ethyl benzene, and xylenes) and heating oil.

Properties of contaminants focused upon during remediation are:

Property	Units	Benzene	Ethylbenzene	Toluene	Xylenes*
Empirical Formula		C_6H_6	C_8H_{10}	C_7H_8	C_8H_{10}
Density @ 20°C	g/cm^3	0.88	0.87	0.87	0.87
Vapor Pressure @ 20°C	mm Hg	100	10	36.7	10
Henry's Law Constant @ 25°C	(atm)	5.59 X 10^{-3}	6.43 X 10^{-3}	6.73 X 10^{-3}	7.04 X 10^{-3} (m^3)/mol
Water Solubility @ 20°C	mg/l	1,800	200	500	200
Log Octanol-Water Partition Coefficient; Log Kow		2.13	3.15	2.69	2.77-3.2
Site Specific Soil-Air Partition Coefficient; Kh /Kd	µg/l air / mg/kg soil		0.48	3.42	0.77
Organic Carbon Partition Coefficient; Koc	ml/g	83	1,100	300	240
Ionization Potential	ev	9.25	8.76	8.82	8.56
Molecular Weight		78.12	106.18	92.15	106.18

*All 3 isomers (M, O, & P)

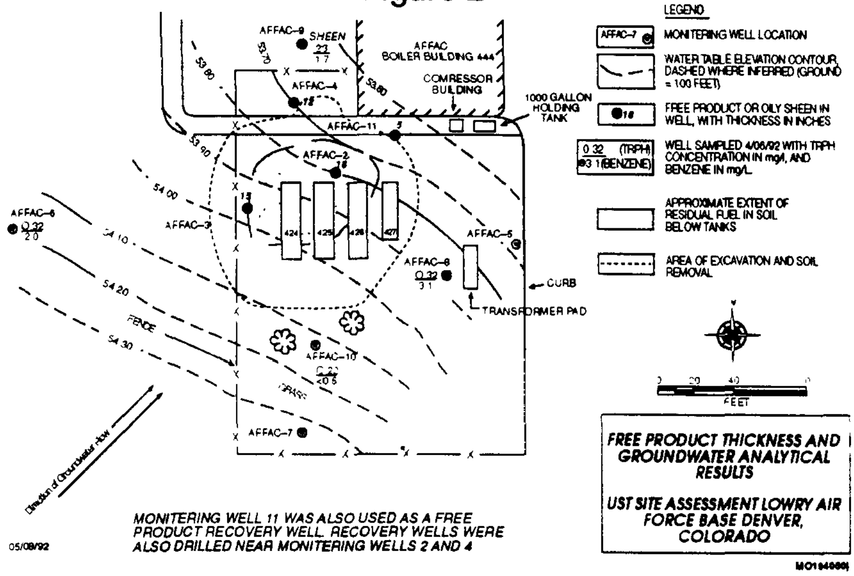
Nature & Extent of Contamination

- 4 USTs (Tanks 424, 425, 426, and 427) were removed.
- It was determined that only Tank 424 leaked.
- Tanks 424, 425, and 426 had a capacity of 24,000 gallons each. Tank 427 had a 6,000 gallon capacity. All 4 tanks were steel.
- Components of the heating fuel oil did not significantly affect the groundwater. Heating fuel oil contains relatively low concentrations of soluble components (such as benzene) compared to lighter petroleum fractions such as gasoline. Groundwater treatment was not deemed necessary, but it was monitored during remediation activities.
- Groundwater benzene concentrations from 4 monitoring wells ranged from 1.7 to 3.1 µg/L. Concentrations of toluene, ethylbenzene, and xylenes were well below State standards and MCLs. Low TRPH concentrations (0.3 mg/L or less) were measured in 3 wells; 23 mg/L of TRPH was observed in the downgradient well.

Contaminant Locations and Geologic Profiles

Remedial investigation field activities at the site included:

Figure 2 Plume (Plan View)



Hydrogeologic Units

- Thicknesses of unconsolidated alluvium >80 feet occur at the location of the DFAS-DE tanks.
- A layer of moist, firm sandy clay occupies the top 10 to 15 feet.
- The next 15 to 80 feet is a medium to coarse-grained sand.
- Aquifer is a water table aquifer.
- Groundwater gradient is roughly 0.4%.
- Approximately 9,000 cubic yards of soil was removed from the excavation. This soil was a combination of course-grained sand and sandy clay.
- Approximately 3,000 cubic yards of sandy clay soil excavated from above the tanks was stockpiled separately and used for backfill of the excavation.
- Clean fill from offsite was used to backfill remainder of the excavation.

Site Conditions

- Elevation is about 5,390 feet.
- Average annual air temperature is 50°F. Diurnal temperature fluctuation averages 29°F. Record high 105°F; record low temperature -30°F.
- 14.81 inches precipitation/year; 58.3 inches of snow/year.
- On the average, the first freeze is around October 12 and the last freeze is around May 5.
- Direction of groundwater flow is from the southwest to the northeast.

Key Soil or Key Aquifer Characteristics Measured

Property	Units	Range or value
Soil moisture content (landfarm)	%	6% to 11%
Hydraulic conductivity	cm/s	1.8 to 78.4 X 10-4
Depth to groundwater	feet	45
Aquifer thickness	feet	>35
Depth to bedrock	feet	>80

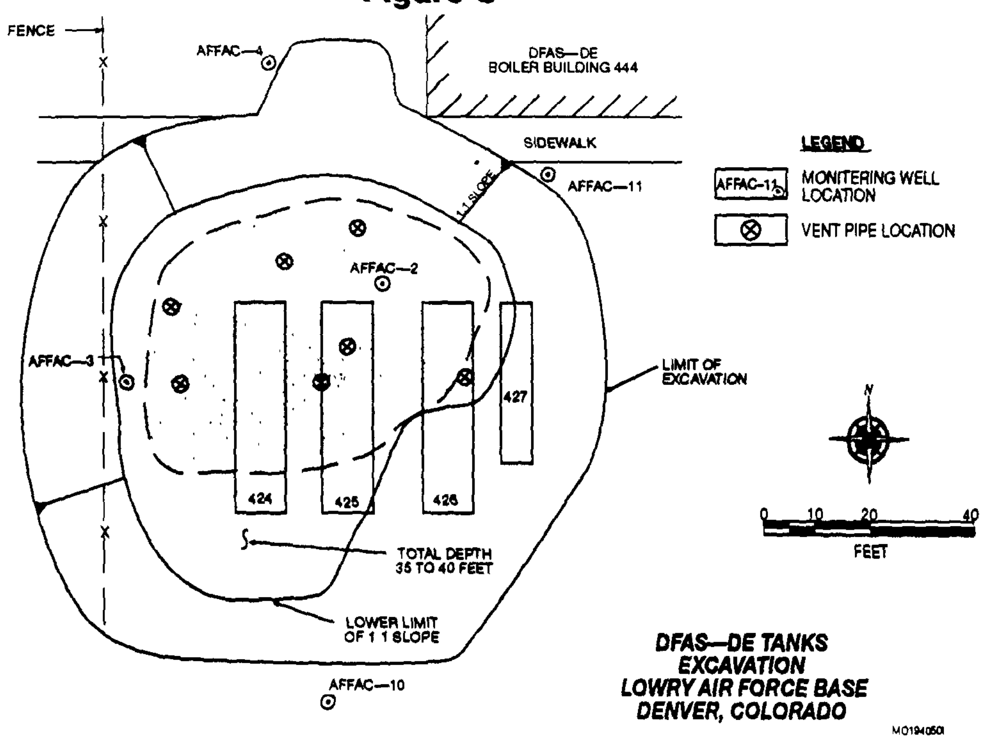
TREATMENT SYSTEM

Three remediation technologies are being used to remediate this site. The three technologies selected complement each other and are not competitive, one with another.

- Landfarming for the soil removed from the excavation.
- Bioventing for the soil remaining in the excavation.
- Product only pumping for the free product found floating on the water table.
- This report addresses landfarming only.

Extent of Excavation

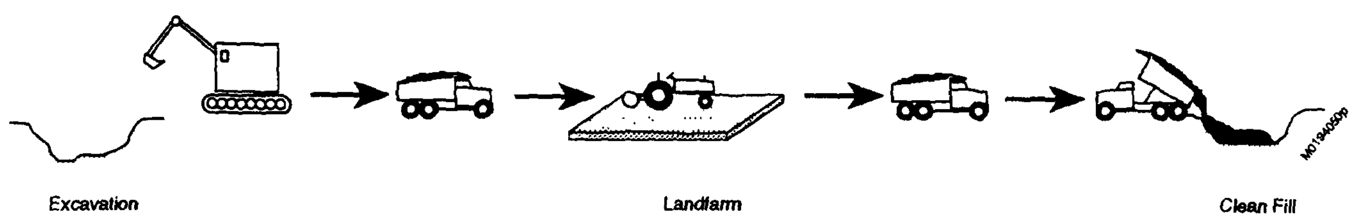
Figure 3



Overall Process Schematic

Figure 4

Process Flow



Key Design Criteria

- Soil berms, 2 feet wide by 2 feet high, were constructed on plastic sheeting used for the landfarming operation and the edges rolled back over the berms.
- Contaminated soil was spread on the plastic sheets to a thickness of 15 inches. Orange synthetic mesh fencing 3 to 4 feet high was installed around the landfarm for security and to prevent animal intrusions.
- The application of agricultural fertilizers to soil used in landfarming operations had C:N:P ratios of 200:10:1 as recommended for hydrocarbon biodegradation. Ammonium nitrate nutrients with this ratio were applied and tilled into the soils once.
- Optimum moisture for biodegradation ranges from 10 to 15% by weight. Moisture was added to the landfarming soils during the dry summer months to maintain this range.
- Based on Lowry AFB soil and contaminant conditions, a minimum landfarming treatment period of 12 to 18 months was expected for reduction of heating oil residuals from 3,100 mg/kg to <500 mg/kg.
- Assuming that a maximum of 10% by weight of the heating fuel oil will volatilize, 1.9 tons of total volatile hydrocarbons could volatilize to the atmosphere during the anticipated landfarming treatment term.

Key Monitored Operating Parameters

- A pilot test was performed to verify treatability.
- TRPH concentrations are used to monitor microbial activity, verify biotreatment of the soil, and document removal of petroleum hydrocarbons from the soil. When TRPH concentrations have been reduced to 500 mg/kg, a letter will be sent to the CDH to confirm successful treatment.

The Treatment System

- A pilot test was conducted over a six month period in 1992 to assess the effectiveness of providing soil amendments to aid in the treatment process.
- 5,400 cubic yards of petroleum contaminated soil was removed from the excavation.
- Soil was removed from below the tanks to a depth of 35 to 40 feet below ground surface.
- Soil that was saturated with fuel oil or had olfactory or PID indications of hydrocarbons present was excavated by a track hoe, hauled to a treatment location on an abandoned paved airstrip, and stockpiled on plastic sheets.
- The stockpiled soils had an average TRPH concentration of 3,100 mg/kg (the maximum observed was 11,000 mg/kg). BTEX was <100 mg/kg.
- The soil is being remediated using above ground biotreatment (landfarming). In landfarming, soil microbes use petroleum hydrocarbons as their primary carbon source. Soil tilling supplies sufficient oxygen to the soils for biodegradation and produces a homogeneous mixture of soil, moisture, and added nutrients. Nutrients including available nitrogen (N), phosphorous (P), and various trace elements were added once by application of an agricultural fertilizer in aqueous solution.
- The thickness of the stockpiled soils during treatment was 14 to 18 inches.
- The soil was aerated with a farm plow to provide oxygen to the soil bacteria. Soil Tilling is performed twice a month from April to November.

PERFORMANCE

Performance Objectives

- There are no RODs or FFAs. However, compliance with EPA and State of Colorado UST regulations is required.
- The soils biotreatment operations will be completed when composite soil samples indicate TRPH concentrations have been reduced to less than 500 mg/kg.

Treatment Plan

- The soil is being remediated using above ground *(ex situ)* biotreatment (landfarming).
- The remediated soils will be used for fill material on Lowry AFB property after soils biotreatment is completed.

Operational Performance

DFAS-DE FULL SCALE LANDFARM SOIL SAMPLING RESULTS

First Samples		Latest Samples	
Dates: Sample I.D.	April 23-27,1992 TRPH* (mg/kg)	Dates: Sample I.D.	Sept. 2, 1993 TEPH† (mg/kg)
AFFAC-SP3	5,400	LF-9/2/93-1	1,700
AFFAC-SP4	5,300	LF-9/2/93-2	1,300
AFFAC-SP5	5,300	LF-9/2/93-3	1,400
AFFAC-SP6	1,200		
AFFAC-SP7	1,700		
AFFAC-SP8	1,300		
AFFAC-SP9	11,000		
AFFAC-SP10	660		
Mean	3,983		1,467

* Total recoverable petroleum hydrocarbons
† Total extractable petroleum hydrocarbons

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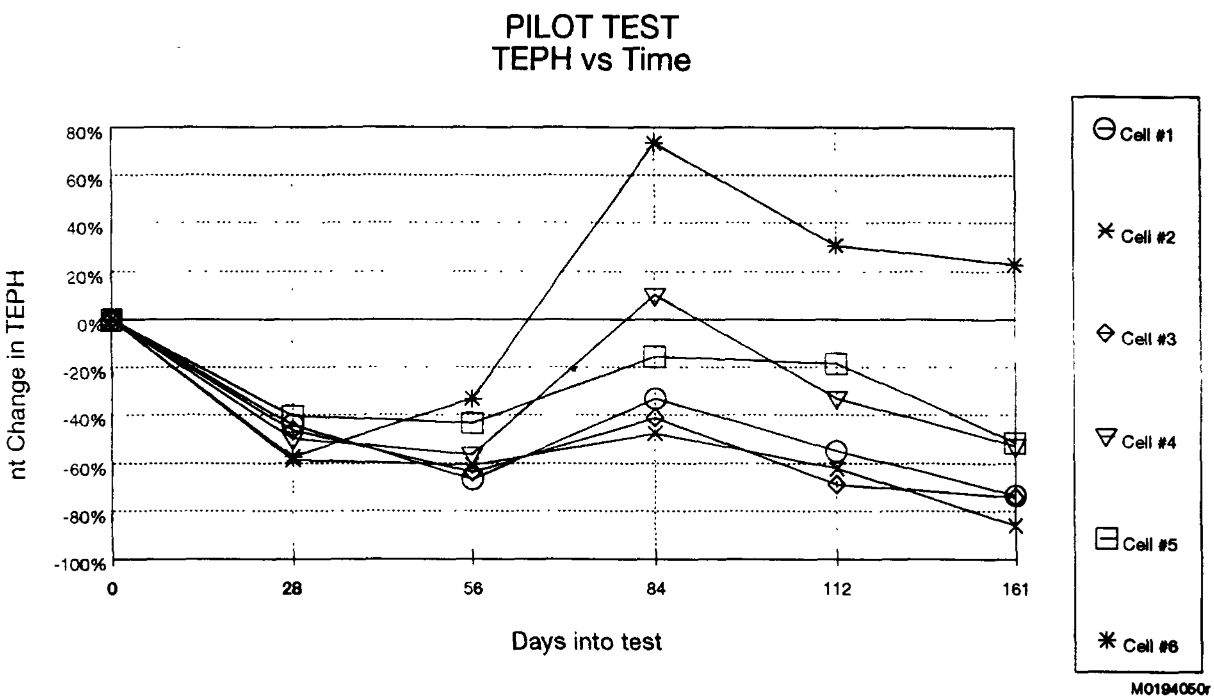
Eight samples of soil stockpiled from the excavation were analyzed for TRPH before being removed to the landfarm. The data labeled "First Samples" in Figure 5 presents this data.

- On September 2nd soil samples from 3 locations in the 100,000 sq. ft. landfarm were analyzed for TEPH. The data labeled "Latest Samples" presents this data.
- The samples from April 1992 indicate that the contaminated soil was not homogeneous before it was placed for landfarming.
- It is difficult to determine the average level of TEPH for the landfarm from only the three samples that were taken on 2 September, 1993.
- Three additional truck loads of diesel contaminated soil were added to the landfarm subsequent to this sampling. This contaminated soil resulted from a 150 gallon diesel fuel spill from a delivery truck.

- **Pilot Test**

  The results of the pilot study showed an uncharacteristic increase in TEPH between weeks 8 and 12. Except for this all samples show a general decrease in TEPH over time. No reason for the increase between weeks 8 and 12 was given.



Treatment Performance

- 9,000 cubic yards of soil were removed from the excavation. 3,000 cubic yards of this were clean soil removed from over the tanks.
- The landfarming project is not complete at this time and the evaluation of the performance of this treatment method is incomplete.
- The data presented in Figure 5, however, suggests that the performance of the landfarming project will be satisfactory.

COST

Capital Costs

Site Work	$14,600
Permitting & Regulatory	$1,500
Startup Costs	$2,400
Subtotal	$18,500
Engineering	$1,500
Project Management	$6,000
Pilot testing	$76,000
Construction/Mobilization/Demobilization	$1,480
Fees @ 1.5%	$277
Cumulative Subtotal	$104,257
Total Capital Costs	$104,257
Annual Capital Cost (over 2.5 years)	$41,700

Estimated Operating Costs (per year)

Laboratory Charges	$500
Maintenance Labor & Parts	$16,640
Monitoring	$1,500
Subtotal	$18,640
Total Annual Operating Cost (estimated)	$18,640
Total Annual Operating & Capital Costs (estimated)	$60,340
Cost/Ton (estimated)	$17

Cost Sensitivities

Effects of Assumption Changes

The estimated cost is subject to the following sensitivities:

	$/ton
• An increase in the landfarm treatment time of 40% (to 3.5 years)	Added $2

REGULATORY/INSTITUTIONAL ISSUES

- The USTs were removed in conformance with American Petroleum Institute Recommended Practice 1604 and the National Fire Protection Association Code 30.
- The EPA and the State of Colorado reviewed all documents produced by this project including the Quarterly Monitoring Reports. In addition, Lowry AFB personnel meet with the EPA and the State of Colorado once/month. Local communities are invited to the monthly environmental meetings.

Cleanup Criteria

The Colorado Department of Health (CDH) Remedial Action Category III (RAC III) Action Levels are:

Compound	mg/kg
Total (Recoverable) Petroleum Hydrocarbons (TRPH)	500
Total Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX)	100

- The CDH's "Basic Standards for Ground Water" includes:

	µg/L
benzene	1
toluene	1,000
ethylbenzene	680
xylenes	none

- The MCL standard for benzene is 5 µg/L, the MCL for xylenes is 10,000 µg/L, but there is no MCL for TPH.
- Shallow groundwater beneath Lowry AFB is not being used as a drinking water supply and there is little or no likelihood that this will change.
- Target Cleanup Levels/Criteria:

Contaminant	mg/L
TPH	500

SCHEDULE

- Landfarming began treatment on 1 July 1992.
- As of September 1992, the estimated time of completion was 2 years.
- As of April 1994 treatment is not complete.

LESSONS LEARNED

Key Operating Parameters

- The key operating parameters are soil moisture, soil oxygen content and temperature.
- The credibility of the 2 September 1992, landfarm soil assessment would have been improved had an adequate, random sampling program been applied at that time. The variability of the TRPH analysis in the initial landfarm soil sample could have been used to determine the number of samples required for the later sampling program.
- The sample collection and laboratory analysis should have been consistent throughout the pilot test or an explanation provided for the inconsistency in the data.

Implementation Considerations and Technology Limitations

- Adequate space for landfarming is required.
- Time is required for biotreatment. For example, it is slower than other treatment method, such as incineration.
- Soils must be excavated for landfarming to be used.

Future Technology Selection Considerations

- Both landfarming (above ground bioremediation) and *in situ* bioventing appear to have been successful at this site, but data, thus far, is not sufficient to make a judgment as to which process performed better.

SOURCES

Major Sources For Each Section

Site Characteristics:	1, 2, 6 and 7
Treatment System:	1 and 7
Performance:	1, 3, 4 and 5
Cost:	8
Regulatory/Institutional Issues:	1
Schedule:	1 and 8

Chronological List of Sources and Additional References

1. *Underground Storage Tanks Site Assessment Report and Corrective Action Plan,* Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., May 1992.
2. *Underground Storage Tanks Site Assessment Report and Corrective Action Plan,* Appendices, Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., June 1992.
3. *Quarterly Monitoring Report, Lowry Air Force Base,* Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., October 1992.
4. *Quarterly Monitoring Report-January 1993,* Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., January 1993.
5. *Quarterly Monitoring Report-November 1993,* Lowry Air Force Base, Denver, Colorado, prepared for Headquarters Air Training Command/DEV, Randolph AFB, Texas, and Armstrong Laboratory/OEB, Brooks AFB, Texas, prepared by Engineering-Science, Inc., December 1993.
6. *RREL Treatability Data Base,* Version 4.0, EPA, November 15, 1991.
7. *Basics of Pump-and-Treat Ground-Water Remediation Technology,* EPA/600/8-90/003, Robert S. Kerr Environmental Research Laboratory, Ada, OK 74820, March, 1990.
8. *Personal Communication with Kent Friesen,* Engineering-Science, Inc., 1700 Broadway, Suite 900, Colorado 80290 (Phone, 303/ 831-8100).

ANALYSIS PREPARATION

This analysis was prepared by:

Stone & Webster Environmental Technology & Service

P.O. Box 5406
Denver, Colorado 80217-5406
Contact: Dr. Richard Carmichael 303-741-7169

REVIEW

Project Manager
This analysis accurately reflects the performance and costs of this remediation

X ____________________

Lt. Tom Williams
3415 CES/DEV
Lowry AFB, CO 80230-3214

Land Treatment at the Scott Lumber Company Superfund Site Alton, Missouri

Case Study Abstract

Land Treatment at the Scott Lumber Company Superfund Site Alton, Missouri

<table>
<tr><td>Site Name:
Scott Lumber Company Superfund Site</td><td rowspan="2">Contaminants:
Polynuclear Aromatic Hydrocarbons (PAHs)
- PAH concentrations were measured as high as 0.326 mg/kg in lagoon water, 12,400 mg/kg in sludge, and 63,000 mg/kg in soils
- Benzo(a)pyrene ranged from 16 to 23 mg/kg at initiation of treatment</td><td>Period of Operation:
December 1989 to September 1991</td></tr>
<tr><td>Location:
Alton, Missouri</td><td>Cleanup Type:
Full-scale cleanup</td></tr>
<tr><td>Vendor:
Christina Consentini
Remediation Technologies, Inc. (ReTeC)
1001 S. 24th Street, W., Suite 105
Billings, MT 59102
(406) 652-7481</td><td rowspan="2">Technology:
Land Treatment
- Construction of land treatment area included a clay liner and berms, run-on swales, and subsurface drainage system
- Retention pond and irrigation system
- Treatment performed using two lifts of soil
- Indigenous microorganisms used to support biodegradation
- Nutrients added to Lift No. 1; none added to Lift No. 2
- Cultivated once every two weeks</td><td>Cleanup Authority:
CERCLA (removal action)
- Action memorandum date: 7/10/87
- Fund Lead</td></tr>
<tr><td>SIC Code:
2491B (Wood Preserving - using Creosote)</td><td>Point of Contact:
Bruce A. Morrison
Remedial Project Manager
U.S. EPA - Region 7
Emergency Planning and Response Branch
25 Funston Road
Kansas City, KS 66115
(913) 551-7755</td></tr>
<tr><td>Waste Source:
Surface Impoundment/Lagoon; Spill</td><td colspan="2" rowspan="2">Type/Quantity of Media Treated:
Soil
- 15,961 tons of soil treated in two lifts
- Classified as sand per USDA system
- Approximately 4% of soil passes a No. 200 sieve</td></tr>
<tr><td>Purpose/Significance of Application:
This was one of the early applications of land treatment at a Superfund site contaminated with creosote compounds.</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
- Action levels in soil were established for total PAHs at 500 mg/kg and for benzo(a)pyrene at 14 mg/kg
- Total PAHs was defined as the sum of 16 specific PAH constituents</td></tr>
<tr><td colspan="3">Results:
- Land treatment achieved specified action levels for PAHs and benzo(a)pyrene
- Lift No. 1 - Total PAHs reduced from 560 to 130 mg/kg, and BAP from 16 to 8 mg/kg, in 6 months of treatment
- Lift No. 2 - Total PAHs reduced from 700 to 155 mg/kg and BAP from 23 to 10 mg/kg, in 3 months of treatment</td></tr>
<tr><td colspan="3">Cost Factors:
- Total Costs for Removal Action - approximately $4,047,000 (including $1,292,000 for the land treatment contractor (over 3 years), $254,000 for laboratory analyses, EPA contractors and EPA oversight)</td></tr>
</table>

Land Treatment at the Scott Lumber Company Superfund Site, Alton, Missouri (Continued)

Description:
From 1973 to 1985, the Scott Lumber Company, located near Alton, Missouri, operated a wood treating facility used to preserve railroad ties with a creosote/diesel fuel mixture. As a result of these operations, soil at the site was found to have been contaminated with polynuclear aromatic hydrocarbons (PAHs) at concentrations as high as 63,000 mg/kg. An Action Memorandum was signed in July 1987, which specified the construction and operation of a land treatment unit (LTU) as a removal action for treatment of PAH-contaminated soils at the site. Cleanup activities were performed in three phases. The first two phases involved decontamination and removal of surface debris and sludge at the site and excavation and stockpiling of contaminated soil at the site. Phase III involved on-site land treatment of the contaminated stockpiled soil.

Land treatment was performed from December 1989 through September 1991, and 15,961 tons of soil were treated during this application. Stockpiled soil was placed in the LTU in two lifts. Approximately 200 lbs per acre of ammonium phosphate fertilizer were added to the first lift to adjust the nutrients in the soil. No nutrient adjustments were made to the second lift. Each lift was cultivated once or twice a week and irrigated, as necessary, to maintain a moisture content between 1% and 4%.

Action levels for the soil at the site, established by EPA, were 14 mg/kg for benzo(a)pyrene (BAP) and 500 mg/kg for total PAHs. Land treatment at the Scott Lumber site reduced levels of BAP and total PAHs to below action levels. In Lift 1, BAP concentrations were reduced from 16 mg/kg to 8 mg/kg and total PAH concentrations were reduced from 560 mg/kg to 130 mg/kg within 6 months. In Lift 2, concentrations were reduced from 23 mg/kg to 10 mg/kg for BAP and from 700 mg/kg to 155 mg/kg for total PAHs within 3 months. The total costs for this removal action were $4,047,000, including $1,292,000 for the land treatment contractor and $254,000 for laboratory analyses. Site demobilization was completed in September 1991.

COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for a land treatment application of contaminated soil at the Scott Lumber Company Superfund site (Scott Lumber), located near Alton, Missouri. From 1973 to 1985, this company operated a wood treating facility that preserved railroad ties with a creosote/diesel fuel mixture. As a result of these operations, soil at the site was contaminated with polynuclear aromatic hydrocarbons (PAHs), which were major components of the creosote/diesel mixture used at Scott Lumber.

An Action Memorandum was signed on July 10, 1987, which specified the construction and operation of a land treatment unit (LTU) as a removal action for treatment of PAH-contaminated soils at the site. Contaminated soil was excavated and stockpiled on site. Land treatment was performed from December 1989 through September 1991, and approximately 15,960 tons of soil were treated in the LTU. The soil in the LTU was cultivated and irrigated on a weekly or bi-weekly basis. Ammonium phosphate fertilizer was added to the first lift to adjust the nutrients in the soil. No nutrient adjustments were made to the second lift. Site demobilization was completed in September 1991.

Action levels established by EPA for soil at the site were 14 mg/kg for benzo-a-pyrene (BAP) and 500 mg/kg for total PAHs.

Land treatment at the Scott Lumber site reduced levels of both BAP and total PAHs to below the soil action levels. In Lift 1, BAP concentrations were reduced from 16 to 8 mg/kg, and total PAH concentrations were reduced from 560 to 130 mg/kg. The most rapid decreases in total PAH concentrations in Lift 1 occurred within the first 6 weeks of treatment. In Lift 2, concentrations were reduced from 23 to 10 mg/kg for BAP and from 700 to 155 mg/kg for total PAHs. The land treatment system was operated for 6 months for Lift 1 and 3 months for Lift 2.

The total removal action costs were approximately $4,047,000, including approximately $1,292,000 in costs incurred by the land treatment contractor.

SITE INFORMATION

Identifying Information

Scott Lumber Company Superfund Site
Alton, Missouri

CERCLIS #: MOD068531003

Action Memorandum Date: 7/10/87

Treatment Application

Type of Action: Removal Action

Treatability Study Associated with Application? Yes *(see Appendix A)*

EPA SITE Program Test Associated with Application? No

Operating Period: 12/89 - 9/91

Quantity of Soil Treated During Application: 15,961 tons

Background

Historical Activity That Generated Contamination at the Site: Creosote wood treating

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

Waste Management Practices That Contributed to Contamination: Surface Impoundment/Lagoon; Spill

SITE INFORMATION (CONT.)

Background (cont.)

Site History: The Scott Lumber Company Superfund (Scott Lumber) site is located within Oregon County in south-central Missouri, approximately one mile east of the town of Alton, Missouri, as shown in Figure 1. From 1973 until 1985, Scott Lumber operated a wood treating facility that preserved railroad ties with a creosote/diesel fuel mixture. A plan view of the site is shown in Figure 2. The process consisted of treating wood using several retort tanks. Waste management practices at the site included discharging creosote contaminated sludge generated during the wood treatment process to an unlined storage lagoon located on site. In addition, an estimated 300 or more gallons of preservative were released during one spill incident, and the direct discharge of creosote waste into the soil was suspected. The creosote sludge was classified as a K001-listed waste by EPA. [1]

Figure 1. Site Location

Site investigations conducted by EPA indicated that the site was principally contaminated with polynuclear aromatic hydrocarbons (PAHs), which are the major components of the creosote/diesel mixture used in the wood preserving operations. Most of this contamination was located within or near the wood treatment area of the site. [1]

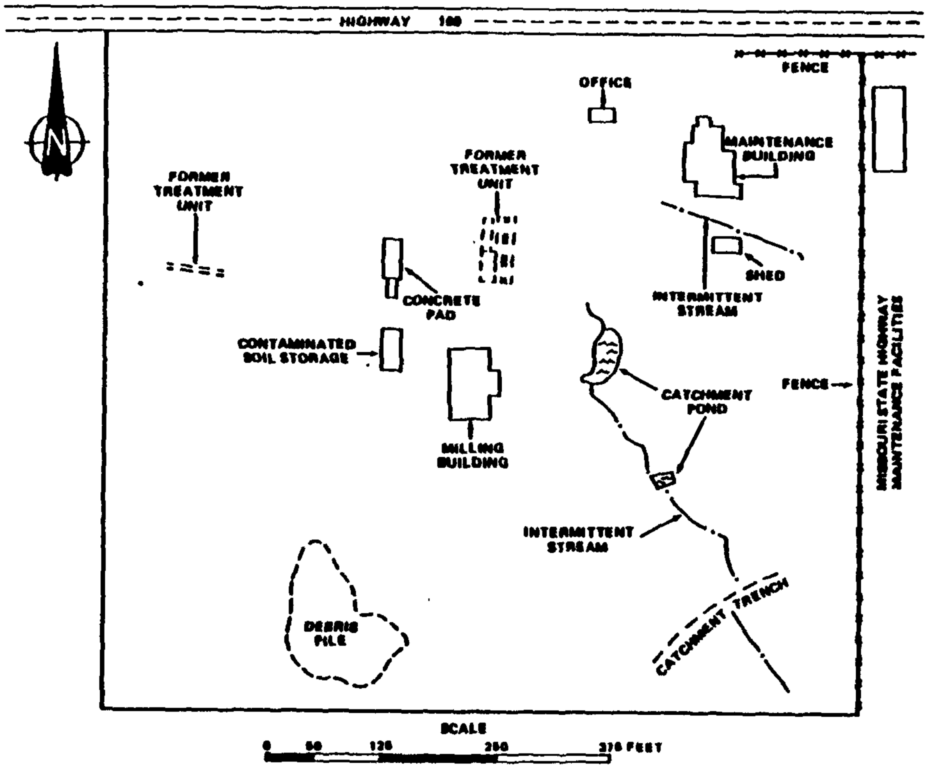


Figure 2. Plan View of SLC Site [4]

SITE INFORMATION (CONT.)

Background (cont.)

Three phases of cleanup activities were conducted at Scott Lumber in response to a July 10, 1987 Action Memorandum. Phase I occurred in 1987 and involved the decontamination and removal of surface debris and sludge at the site. Phase II occurred from July to September 1988 and involved the excavation and stockpiling of contaminated soil identified at the site. Phase III occurred from 1989 to 1991 and involved the on-site land treatment of contaminated soil. [1] This report focuses on Phase III of the cleanup activities.

Regulatory Context: Action levels for the soil at the site were established by EPA and approved by the Agency for Toxic Substances and Disease Registry in 1987. The action levels were 14 mg/kg for benzo-a-pyrene (BAP) and 500 mg/kg for total PAHs. [1,2]

Total PAHs refer to the 16 constituents listed in Appendix B of this report.

Remedy Selection: Three methods were considered for remediation of PAH contamination at the site: 1) excavation and off-site disposal; 2) encapsulation with on-site disposal; and 3) land treatment. On-site land treatment was determined to be the best alternative because it was the most cost-effective method for permanently eliminating the identified contaminants at the site, and it was an innovative treatment technology. [2,4]

Site Logistics/Contacts

Site Management: Fund Lead

Oversight: EPA

On-Scene Coordinator:
Bruce A. Morrison
U.S. EPA - Region 7
Emergency Planning and Response Branch
25 Funston Road
Kansas City, Kansas 66115
(913) 551-7755

Treatment System Vendor:
Christina Cosentini
Remediation Technologies, Inc. (ReTeC)
1001 S. 24th Street W., Suite 105
Billings, Montana 59102
(406) 652-7481

MATRIX DESCRIPTION

Matrix Identification

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

Contaminant Characterization

Primary Contaminant Group: Polynuclear Aromatic Hydrocarbons (PAHs)

PAHs were found in the water and sludges of the unlined storage lagoon and soil at the site. PAH concentrations were measured as high as 0.326 mg/kg in lagoon water, 12,400 mg/kg in sludge, and 63,000 mg/kg in soils. [4]

Concentrations for individual PAHs in untreated soils, prior to excavation, are shown in Table 1.

MATRIX DESCRIPTION (CONT.)

Contaminant Characterization (cont.)

Table 1. Contaminant Characterization [4]

PAH Constituent	Soils Average (mg/kg)	Soils Range (mg/kg)
Naphthalene	173	0.15 to 2,000
Acenaphthylene	43	0.34 to 440
Acenaphthene	780	0.051 to 7,500
Fluorene	893	0.47 to 10,000
Phenanthrene	1,700	0.48 to 31,000
Anthracene	163	0.45 to 14,000
Fluoranthene	836	0.31 to 17,000
Pyrene	755	0.19 to 13,000
Benzo(a)anthracene	243	0.23 to 4,300
Chrysene	262	0.61 to 4,900
Benzo(b)/(k)fluoranthene	236	0.62 to 3,200
Benzo(a)pyrene	130	0.74 to 1,600
Indeno(1,2,3-cd)pyrene	75	0.47 to 770
Dibenzo(a,h)anthracene	16	0.37 to 180
Benzo(ghi)perylene	90	0.35 to 830

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 presented in Table 2. A particle size distribution of soils at Scott Lumber, using U.S. standard sieves, is shown in Table 3.

Table 2. Matrix Characteristics [9]

Parameter	Value	Measurement Method
Soil Classification	Sand (Gravel and sand with minor silt fractions)	USDA
Clay Content and/or Particle Size Distribution	See below	—
pH	6.8 to 8	—
Field Capacity	Not available	—

Table 3. Particle Size Distribution [9]

Sieve No.	% Finer
10	54.89
20	27.92
40	17.07
60	10.35
100	6.22
200	4.14
Pan	0.00

Site Geology/Stratigraphy

Unconsolidated soils near the ground surface primarily consist of a cherty clay interspersed with dense clay. Chert is a biochemical rock that consists of fibrous chalcedony, quartz, and silica. The total thickness of the unconsolidated soils that overlie the area's porous limestone is not known. [4]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology Type

Land Treatment

Supplemental Treatment Technology Types

None

Land Treatment System Description and Operation

Construction of the land treatment unit at Scott Lumber began in 1989 and involved the following activities:

- Site preparation;
- Construction of a clay liner in the land treatment area;
- Construction of berms, run-on swales, monitoring wells, and lysimeters around the land treatment area;
- Installation of a subsurface drainage system in the land treatment area;
- Construction of a water retention pond;
- Installation of an irrigation system for the land treatment area;
- Construction of a fence around the land treatment area; and
- Placement of contaminated soil in the land treatment area.

The locations of the land treatment area, contaminated soil stockpile area, and water retention pond, as well as the subsurface drainage layout, are shown on Figure 3.

Site preparation activities included removing three buildings from the proposed land treatment area and relocating sawdust and scrap wood debris at the site prior to regrading the surface topography. While regrading, a new area of subsurface creosote-contaminated soil, approximately 100 feet in diameter, was discovered near what was once the retention pond.

Approximately 5,000 tons of contaminated soil were excavated from this area and added to the stockpile of soil to be remediated. The area was backfilled with clean fill material. [1,2]

Construction of a clay liner in the land treatment area involved the compaction of the top 1 foot of in-situ soil and the addition of a compacted 2-foot clay layer. The in-situ and fill clay layers totaled 3 feet. To inhibit fluid permeability within the clay layers, the compacted clay surface was broken up and loosened between placement of 6-inch lifts, and soil moisture was maintained at 1% to 4% greater than the optimum determined by the Modified Proctor Test. Perimeter berms were constructed around the LTU to the same specifications as the clay liner. [1,2]

An underdrain system was constructed above the clay layer to collect and drain water to a retention pond. The system consisted of a 9- to 10-inch thick sand layer containing a

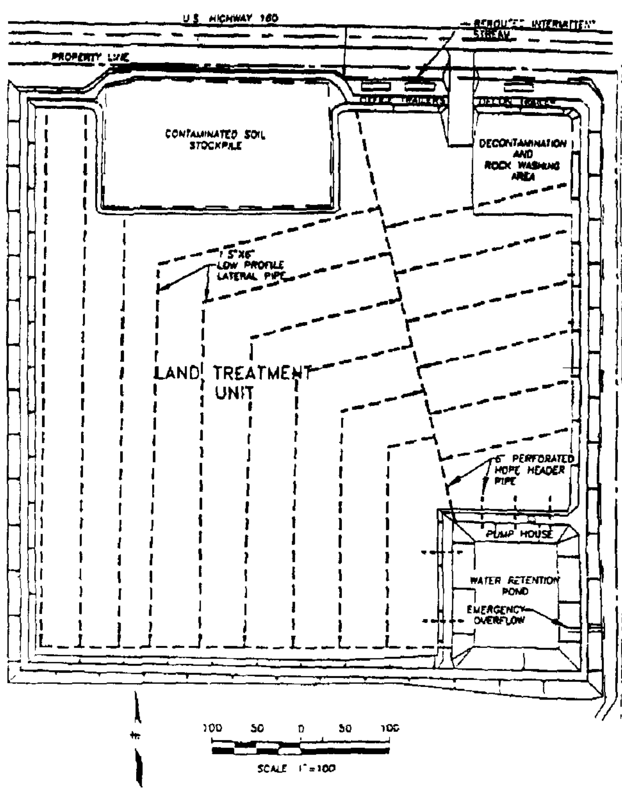


Figure 3. LTU at Scott Lumber [1]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Land Treatment System Description and Operation (cont.)

drainage pipe network consisting of HDPE perforated pipe 1.5 inch thick by 12 inches wide wrapped in a geotextile membrane. The HDPE pipe was connected to 6-inch header pipes placed within the top 6 inches of the clay liner. These header pipes were also perforated and drained to the retention pond. Each header pipe was surrounded by gravel backfill and covered with a geotextile membrane. Figure 3 shows the subsurface drainage network within the LTU. [1 and 2]

A retention pond was constructed in the southeast corner of the LTU to receive the potentially contaminated LTU runoff water collected by the underdrain system. It was lined with a 40-mil HDPE liner that overlay a 3-inch sand cushion, and had a storage capacity of approximately 1 million gallons. When the capacity of the retention pond was exceeded during rainy periods, excess water was discharged to the Alton Wastewater Treatment Plant located adjacent to the site. [2]

A 2- to 4-inch layer of topsoil was placed on top of the underdrain layer to guard against tilling damage and to decrease the leaching potential of contaminated soil. A cross section of the LTU, showing the location and thickness of individual soil layers, is presented in Figure 4. [2]

LTU Operation

Contaminated soil from the stockpile area was placed in the LTU in 2 lifts. The first lift was placed into the treatment area in December 1989, and treatment occurred from May to November 1990 (6 months). This lift consisted of approximately 9,000 tons of soil and averaged 9 inches in thickness. The remaining stockpiled soil was placed on the LTU in December 1990 and May 1991, and treatment of the second lift occurred from May to August 1991 (3 months). The second lift consisted of approximately 7,000 tons of soil and averaged 7 inches in thickness. [1 and 2]

After the first lift of soil was placed in the treatment area, a portable irrigation system was installed. The irrigation system consisted of a 4-inch aluminum pipe placed along the base of the southern LTU berm. Water was pumped from the retention pond, through this line, to a moving wheel lateral line. The lateral line was manually rolled east to west at 40-foot intervals along the southern berm pipe, and water was distributed to the LTU from the lateral line through impulse sprinkler heads spaced every 40 feet. During the summer months, the LTU was irrigated approximately once a week. [2] The irrigation activities for the first lift began during the first week of June 1990, and for the second lift during the third week of May 1991. [8]

Contaminated Soil to be Treated
Zone of Incorporation (Topsoil) 2 to 4 inches
Sand Layer (Including Underdrain Pipe Network) 10 inches
Compacted Clay Liner 2 feet
In-situ Compacted Clay Liner 1 foot

Figure 4. LTU Cross Section [2]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Land Treatment System Description and Operation (cont.)

Following placement of each lift in the LTU, large rocks and debris were removed from the contaminated soil, utilizing an alternating series of cultivating and rock and debris collecting activities. Cultivation broke up the soil and brought rocks, wood, and other debris to the surface, where they were collected with a tractor-mounted Anderson Rock Picker. The rocks and debris collected that were greater than 3 inches in length were placed in a designated stockpiling area for segregation and decontamination. [2] The tilling activities for the first lift began during the first week of June 1990, and for the second lift during the third week of May 1991. [8]

Treatability study results indicated that sufficient indigenous microorganisms existed in the soil at this site to support biodegradation. [4]

Approximately 200 pounds per acre of granular, ammonium phosphate fertilizer was applied to the first lift to obtain a ratio of soil organic content to nitrogen to phosphorus of 100:2:0.4. No nutrient adjustments were necessary for the second lift. [2]

Each lift was cultivated to aid the aerobic bioremediation process. The soil was cultivated using farm equipment (chisel plow, tiller, or subsoil ripper) for specific soil conditions. For example, the subsoil ripper was used to break up thick, compacted, silty clays, and the chisel plow was used for routine soil cultivation. Each lift was cultivated approximately once a week while rock and debris removal was occurring, and twice a week when no rock and debris removal took place. [2]

Soil samples collected in October 1990 indicated that total PAH concentrations were approximately 130 mg/kg and BAP concentrations were approximately 8 mg/kg and treatment of Lift #1 was complete. Treatment of Lift #2 was completed in August 1991, and final concentrations were reported to be 155 mg/kg for total PAH and 10 mg/kg for BAP. Site closure was completed in the autumn of 1991; activities included the disposal of debris at the Butler County landfill, regrading portions of the site, seeding and fertilizing the site, and demobilizing office trailers and equipment. [1]

Health and safety requirements for this operation included compliance with the permissible exposure limit for PAHs set by the Occupational Safety and Health Administration.

Groundwater Monitoring
Groundwater monitoring was conducted throughout operation of the LTU. The groundwater monitoring program was conducted to detect any migration of PAHs from the LTU to the groundwater. Four shallow groundwater monitoring wells screened between 30 and 35 feet below ground surface were installed in each corner of the LTU. Two deep monitoring wells screened between 95 and 100 feet below ground surface were installed in the northwest (upgradient) and southeast (downgradient) corners of the site. Shallow wells were based on the depth to the groundwater, while deep wells were based on depths of nearby private wells. [8]

Before placement of the compacted 2-foot clay layer, four groundwater lysimeters were installed inside the perimeter berms to monitor contaminant migration through the clay liner. To minimize the development of a migration route, the lysimeter collection tubes were laterally trenched to locations outside the LTU. [2]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Operating Parameters Affecting Treatment Cost or Performance [1,2]

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

Table 4. Operating Parameters [1,2, 9]

Parameter	Value	Measurement Method
Mixing Rate/Frequency	Once a week during rock removal, twice a week otherwise	—
Moisture Content	10 to 20%	—
pH	6.8 to 8	—
Residence Time (for treatment)	Lift #1 - 6 months Lift #2 - 3 months	—
Temperature	No data available	—
Hydrocarbon Degradation	72 mg/kg/mo. for Lift #1 182 mg/kg/mo. for Lift #2	Calculated
Nutrients and Other Soil Amendments	Soil organic content:nitrogen:phosphorus adjusted to 100:2:0.4 for Lift #1 No nutrient adjustment for Lift #2	Not known

Timeline [1,2,6]

The timeline for this application is presented in Table 5.

Table 5. Timeline [1,2,6]

Start Date	End Date	Activity
1973	1985	Scott Lumber Co. operated
July 10, 1987	—	Action Memorandum signed
August 1987	November 1987	Phase I of removal action - decontamination and removal of surface debris
July 1988	September 1988	Phase II of removal action - excavation and stockpiling of contaminated soil
1989	1991	Phase III of removal action - land treatment of contaminated soil
December 1989	—	First lift - soil placed in LTU
May 1990	November 1990	Treatment process (filling, rock removal/washing, nutrient adjustment, irrigation) of first lift
December 1990	—	Second lift - first load placed in LTU
May 1991	—	Second lift - second load placed in LTU
May 1991	August 1991	Treatment process (no nutrient adjustment) of second lift
September 1991	—	Site demobilization complete

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

Action levels for the soil at the site were established by EPA. The action levels were 14 mg/kg for benzo-a-pyrene (BAP) and 500 mg/kg for total PAHs. [1 and 2] Total PAHs refers to the 16 PAH constituents listed in Appendix B to this report.

Additional Information on Goals

Action levels for soil at the site were based on McClanahan's relative carcinogenic risk of BAP compared to 2,3,7,8-tetrachlorodibenzo-p-dioxin, as well as action levels previously approved by the Agency for Toxic Substances and Disease Registry for cleanup of soil at similar sites. [2]

Treatment Performance Data

Between April and November 1990, EPA collected soil samples from a 5,000-square foot subplot within Sampling Area F shown on Figure 5. This subplot measured 50 feet north/south by 100 feet east/west and was located on the east side of Sampling Area F. Three 50-ml aliquot samples were collected every two weeks during treatment of the first lift from quadrants north, south, and east. These samples were analyzed for total PAHs by GC/MS analytical Method 3230.2A, an EPA Region 7 modification of a CLP analytical method for extraction and analysis of water and solids for semivolatile organic compounds. [7] Samples were collected within Sampling Area F because it was conveniently located near the decontamination and office areas, was out of the way of most facility operations, and the marker flags placed within the subplot could be lined up with permanent markers on the adjoining berm. [2 and 5]

The individual PAH analytical results by sample date for Lift #1 are presented in Appendix B by subplot location. Average concentrations were calculated for each PAH constituent measured in the three Subplot F quadrants, as shown in Appendix B, by sample date. Total PAHs were calculated for each sample date by summing the analytical results for all 16 PAH constituents shown in Appendix B. The averages of the total PAH concentrations were calculated and plotted against each sample date, as shown in Figure 6, and average BAP concentrations were plotted against each sample date, as shown in Figure 7.

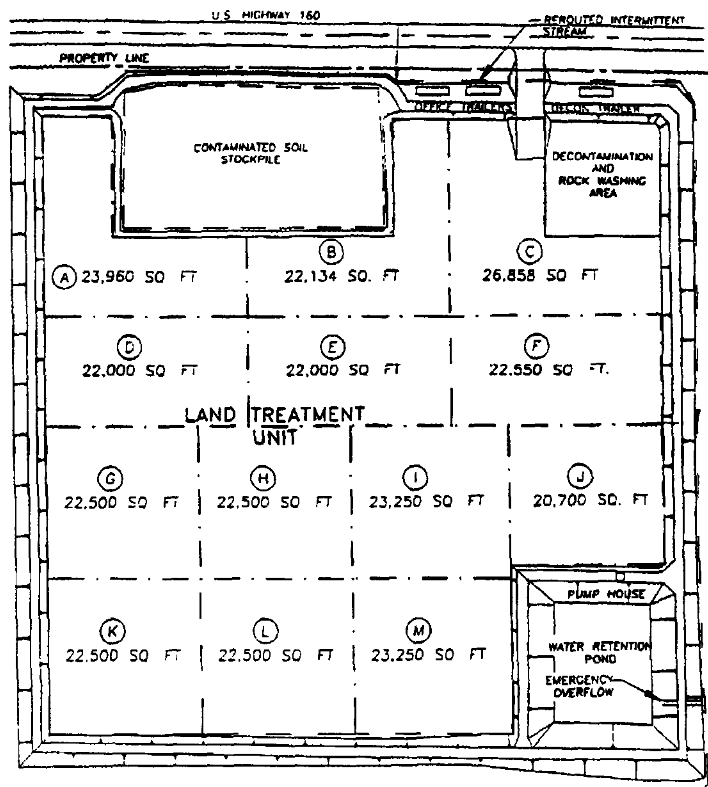


Figure 5. Sampling Locations [1]

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

In Lift #2, concentrations were reduced from 23 to 10 mg/kg for BAP and from 700 to 155 mg/kg for total PAH. Initial BAP and total PAH concentrations for Lift #2 were collected in May 1991. [1]

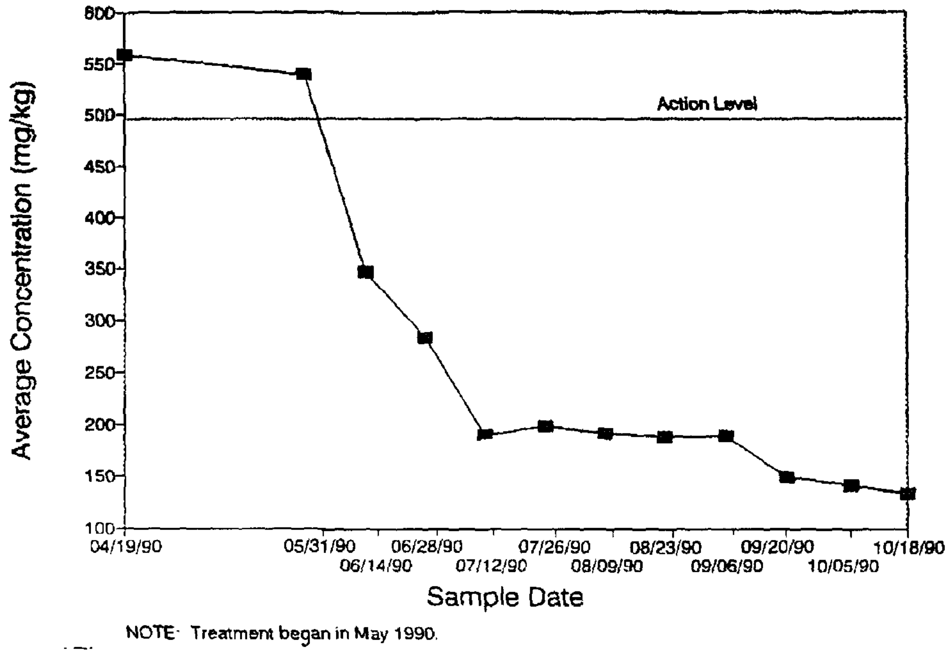


Figure 6. Total PAH Concentrations During Treatment of Lift No. 1 (based on Appendix B)

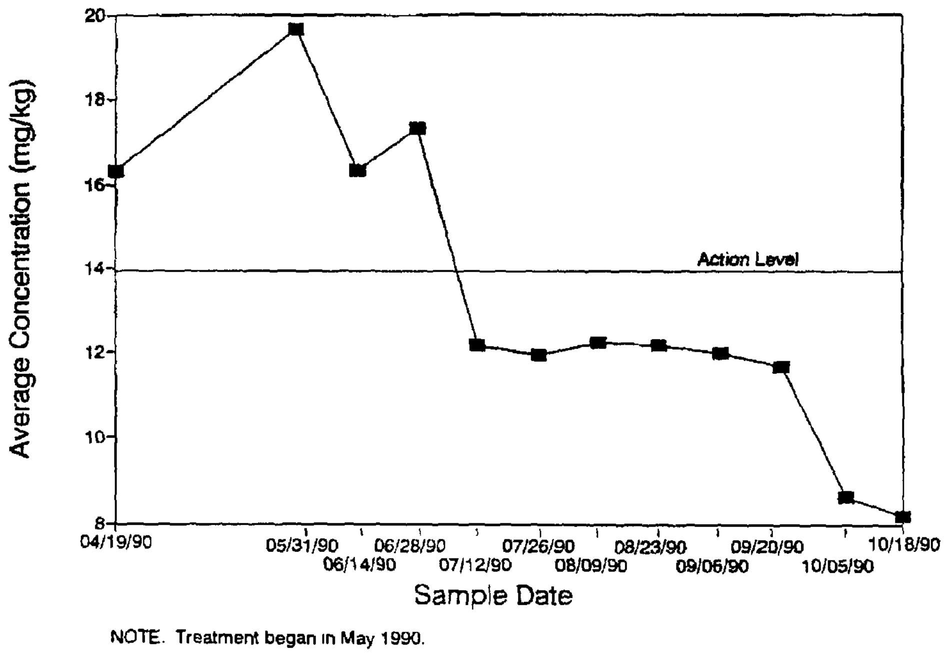


Figure 7. BAP Concentrations During Treatment of Lift No. 1 (based on Appendix B)

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Groundwater monitoring was conducted on a quarterly basis during operation of the LTU. No data are available on the results of groundwater monitoring.

During initial soil loading and LTU system start-up, air monitoring of PAHs was conducted using NIOSH Method 5515. Gilian pump monitors placed on equipment used during the cultivating and loading operations detected airborne PAHs at concentrations as high as 6.8 $\mu g/m^3$ during an 8-hour sampling period. [2]

Performance Data Assessment

A review of analytical data for treatment of soil in Subplot F of Lift No. 1 indicated that average total PAH concentrations decreased from 560 to approximately 130 mg/kg within 6 months of treatment, and the average BAP concentration decreased from 16 to approximately 8 mg/kg in the same time frame. A rapid decrease in average total PAH and BAP concentrations occurred within the first six weeks of the treatment, when the average total PAH concentration decreased from approximately 560 to 190 mg/kg, and the average BAP concentration decreased from approximately 20 to 12 mg/kg. The action level for total PAH was reached after a few days of treatment, and, for BAP, within the first 6 weeks of treatment.

A review of the analytical data for a 3-ring PAH (phenanthrene) shows a reduction from 65 to 5 mg/kg (92%) over a 6-month time frame, while data for a 5-ring PAH (indeno(1,2,3-cd)pyrene) shows a reduction from 19 to 6 mg/kg (68%) over the same period. These data show that biodegradation is faster for PAH constituents with fewer benzene rings (in this case, biodegradation for phenanthrene was faster than for indeno(1,2,3-cd)pyrene).

A review of air monitoring data for PAHs indicated that the maximum concentration measured was less than the permissible exposure limit set by the Occupational Safety and Health Administration.

Performance Data Completeness

Soil samples were collected during treatment of a small area that represented slightly greater than 1% of the total LTU area.

Subplot F was sampled on a 2-week basis during treatment of the first lift to monitor treatment performance. Soils in Lift No. 1 were assumed to be homogeneous with respect to PAH concentrations. Subplot F was selected for sampling because of ease of accessibility, proximity to the decontamination area, and the ability to leave marker flags on the subplot.

Constituent-specific analytical data for the 16 PAHs of interest during this cleanup are only available for treatment of the first lift.

Performance Data Quality

Laboratory analytical data are accompanied by statements certifying that the data have met all quality assurance requirements unless otherwise indicated in the data packages. Duplicate samples were collected from each quadrant and are included in each data package. [6]

TREATMENT SYSTEM COST

Procurement Process

The removal activities at Scott Lumber were financed by EPA. EPA contracted Remediation Technologies, Inc. to conduct the land treatment activities at the site. [1]

TREATMENT SYSTEM COST (CONT.)

Treatment System Cost [1]

Total removal action costs at Scott Lumber were approximately $4,047,000. Because little information was provided on the specific elements included in these costs, a breakdown of these costs into the elements of an interagency Work Breakdown Structure (WBS) was not completed at this time. Actual costs for treatment activities (i.e., those incurred by the land treatment contractor) are shown below by year:

1989	$690,000
1990	$352,000
1991	$250,000
TOTAL	$1,292,000

The $1,292,000 in total costs for treatment activities corresponds to approximately $81/ton of soil treated, for the 15,961 tons of soil treated in this application.

Additional costs at Scott Lumber were incurred by the ERCS contractor ($1,666,000); TAT ($207,000); EPA Direct ($187,000); EPA Indirect ($395,000); laboratory analyses - CLP ($254,000); and ERT/ERU ($46,000).

Cost Data Quality

Total cost information was provided by the EPA On-Scene Coordinator (OSC) for this project, and includes cost for several activities. The specific cost elements included in each activity are not available at this time.

Vendor Input

Costs for similar operations were estimated by the treatment vendor to range from $50 to $100 per cubic yard of soil treated for quantities in excess of 3,000 cubic yards.[21]

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- Total removal action costs were approximately $4,047,000, including approximately $1,292,000 in costs incurred by the land treatment contractor.
- The discovery during construction of the LTU and resulting excavation and treatment of an additional 5,000 tons of contaminated soil added approximately $65,000 to the contractor costs and delayed the construction of the LTU by one month.
- The OSC indicated that contract expenditures were minimized during this remediation because the ERCS contractor project manager was not required to be present on site during routine bioremediation activities.
- The OSC identified calculating volume, rather than mass, as a preferred method to quantify the amount of soil to be treated in the LTU. Weighing truckloads of soil was more costly than surveying soil stockpiles or using overflights to determine volume.
- The treatment at Scott Lumber was completed using 2 lifts; the system was constructed using a clay liner and underdrain system.

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Performance Observations and Lessons Learned

- The cleanup goal for total PAHs at Scott Lumber was established in terms of the sum of the concentrations for 16 specific polynuclear aromatic hydrocarbons. Cleanup goals for this application were specified as 500 mg/kg for total PAHs and 14 mg/kg for benzo(a)pyrene, one of the 16 specified PAHs.
- The cleanup goals were achieved within 6 months for Lift #1 and 3 months for Lift #2.
- Land treatment at the Scott Lumber site reduced total PAH concentrations from 560 to 130 mg/kg, and BAP from 16 to 8 mg/kg, in Lift #1. In Lift #2, concentrations were reduced from 700 to 155 mg/kg for total PAH and from 23 to 10 mg/kg for BAP.
- The most rapid decreases in PAH concentrations in Lift 1 occurred within the first 6 weeks of treatment.

Other Observations and Lessons Learned

- This was one of the early applications of land treatment of creosote-contaminated soil at a Superfund site.
- A laboratory/demo-scale treatability study conducted using site soils demonstrated the feasibility of bioremediation for treatment of creosote-contaminated soils at Scott Lumber.
- Additional information provided by the OSC and Contracting Officer concerning the procurement and contracting processes at the Scott Lumber site (and other removal action sites) is provided in Reference 10. Reference 10 is available from the U.S. EPA National Center for Environmental Publications and Information (NCEPI), P.O. Box 42419, Cincinnati, OH 45242; (fax orders only - (513) 489-8695).

REFERENCES

1. Federal On-Scene Coordinator's Report, Scott Lumber Company Site, non-NPL, Alton, MO, July 10, 1987 - October 1, 1991. Bruce A. Morrison, U.S. Environmental Protection Agency, January 15, 1993.
2. On-Site Bioreclamation of Creosote-Contaminated Soil at the Scott Lumber Site. Bruce A. Morrison, U.S. Environmental Protection Agency. Paper 92-27.04, from the Air and Waste Management Association Conference, 85th Annual Meeting and Exposition, June 1992.
3. Memorandum Request for Exemption from the $2 Million Limitation at the Scott Lumber Company Site, Alton, MO. Morris Kay to J. Winston Porter, U.S. Environmental Protection Agency, 15 July 1988.
4. Final Report, Feasibility of Biological Remedial Action at Scott Lumber Company Site, Alton, MO. Ecology and Environment, Inc., March 1988.
5. Personal communication, Bruce A. Morrison, U.S. Environmental Protection Agency, 11 April 1994.
6. Analytical data reports: 4/19/90, 5/31/90, 6/14/90, 6/28/90, 7/12/90, 7/26/90, 8/9/90, 8/23/90, 9/6/90, 9/20/90, 10/5/90, 10/18/90; provided by Bruce A. Morrison.
7. Standard Operating Procedure; Extraction and Analysis of Water and Soils for Semivolitale Organic Compounds, September 21, 1989.

REFERENCES (CONT.)

8. Memorandum; Response to Information Request for Scott Lumber Site, Bruce Morrison to Linda Fiedler, U.S. EPA, January 5, 1995.

9. Letter from Christina Cosentini to Linda Fiedler, Scott Lumber information request, February 3, 1995.

10. Procuring Innovative Treatment Technologies at Removal Sites: Regional Experiences and Process Improvements, U.S. EPA, Publication 542/R-92/003, August 1992.

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 Corporation under EPA Contract No. 68-W3-0001.

APPENDIX A—TREATABILITY STUDY RESULTS

Identifying Information

Site Identifying Information
Site Name: Scott Lumber Company
Site Location: Alton, Missouri
CERCLIS #: MOD068531003
Action Memorandum Date: 7/10/87

Type of Treatability Study
Laboratory/Demo-Scale of Soil Bioremediation

Treatability Study Strategy

The purpose of this treatability study was to assess the feasibility of bioremediation for creosote-contaminated soil by: (a) growing a microbial culture capable of degrading PAHs; (b) demonstrating that the site soil was not toxic to the microbes; and (c) evaluating the relative biodegradability of PAH constituents.

Three test runs were completed during this study. The overall philosophy of conducting the three runs was to measure system performance under differing conditions of soil and creosote loadings and reloadings. As shown in Table 1, Run No. 1 received an initial creosote loading of 1% and no additional loadings. The purpose of this run was to observe the biodegradation of PAH constituents with no soil present. In addition, after microbes were killed (Week 4), Run No. 1 was used as a control run to assess the potential for PAH removal by processes other than biodegradation. Run No. 2 received an initial creosote loading of 0.5% and then was reloaded with 0.5% creosote at 2 and 4 weeks. The purpose of this run was to investigate the potential enhancement of biodegradation of higher-molecular-weight PAHs by the addition of more easily degraded, lower-molecular-weight PAHs. Run No. 3 received the same creosote loadings as Run No. 2 but was also loaded and reloaded (at times of creosote loading) with 10% clean soil. The purpose of this run was to investigate the potential inhibition of biodegradation due to possible soil toxicity. [4]

Table A-1. Schedule for Loadings and Reloadings Used in Treatability Study [4]

Week	Creosote and Soil Loading (%)*		
	Run #1	Run #2	Run #3
0 (start)	1% creosote 0% soil	0.5% creosote 0% soil	0.5% creosote 10% soil
1	No loading	No loading	No loading
2	No loading	0.5% creosote reloading	0.5% creosote 10% soil reloading
3	No loading	No loading	No loading
4	Microbes killed	0.5% creosote reloading	0.5% creosote reloading 10% soil reloading
5	0.5% creosote loading	No loading	No loading
6	Run terminated	Run terminated	Run terminated

**All loadings are in weight/volume percentages.*

Treatment System Description

Bioremediation System Description and Operation
The bioremediation system consisted of three aqueous bioreactors and related equipment. The bioreactors used were 10-20 liter plexiglass vessels, which were aerated and mixed using humidified air. The three bioreactors were placed in a walk-in environmental chamber which was kept at a constant temperature of 30°C. [4]

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

Treatment System Description (cont.)

Microbial cultures used in this study were grown using sludge from the site and a nearby publicly owned treatment works (POTW). System operation involved loading the bioreactors with an aqueous slurry of clean soil from the site, creosote, inorganic nutrients, and microbial cultures. The three bioreactors were loaded and reloaded with varying quantities of soil and creosote. Bioreactors were maintained at a pH of 7.0 using sulfuric acid, and operated for approximately 6 weeks. [4]

Procurement Process

Ecology & Environment, Inc. was tasked by EPA Region VII through a Technical Assistance Team (TAT) Zone II contract to perform the treatability study as a Technical Assistance Project (TDD No. TPM-8801-001).

Treatment Performance Results

Treatment Performance Data

Treatment performance data were collected for oxygen uptake rate, PAH constituent content, solids content, and organic carbon content. Oxygen uptake was measured to indicate microbial activity levels. Microbial respiration was the only mechanism for consuming dissolved oxygen in the bioreactors. A gas chromatograph coupled with flame-ionization detector (EPA Method 610) was used to measure the concentrations of PAH constituents. Solids content was analyzed by measuring the concentrations of dissolved solids (DS) and volatile suspended solids (VSS). DS measurements indicated the amount of inorganic nutrients and creosote present in the bioreactors, and VSS measurements were used as a rough estimate of the microbial community size. Results from organic carbon analyses yielded values for both soluble organic carbon (SOC) and total organic carbon (TOC). These measurements indicated the amounts of dissolved and total creosote, respectively, in each bioreactor. Samples for each of these parameters were collected from the bioreactors by dipping a beaker into the solution and collecting liquid free of froth and organic sheen.

Data on the oxygen uptake rate for the 3 runs, as a function of time, are presented in Table 2. Data on the concentrations for both individual and total PAH constituents for the 3 runs, as a function of time, are presented in Table 3. The DS, VSS, SOC, and TOC concentrations for the 3 runs, as a function of time, are presented in Figures 1-4, respectively [note - Bioreactor 1 shown on the figures corresponds with Run No. 1, Bioreactor 2 with Run No. 2, and Bioreactor 3 with Run No. 3]. [4]

Performance Data Assessment

The oxygen uptake data indicate that a microbial culture capable of degrading PAHs was grown during this study. Oxygen was actively consumed in each of the bioreactors, and rates of oxygen consumption increased significantly after reloadings in response to substrate addition. Run Nos. 2 and 3, which were reloaded during the run, experienced the greatest increases in oxygen consumption rates. Since creosote was the only organic substrate present and no physical or chemical mechanism was identified for oxygen consumption, the uptake of oxygen in the bioreactors was attributed to biodegradation of PAHs. VSS results show that the size of the microbial community (biomass) increased over the course of the study in proportion to creosote reloading, indicating that a microbial community capable of degrading PAHs had been established.

In addition, the oxygen uptake data, which showed comparable results for Run No. 3 (which included loading and reloadings with 10% soil) as for Run Nos. 1 and 2, indicate that site soils were not toxic to the microbial community.

However, with respect to the biodegradation of PAHs, the results of the treatability study did not establish the relative biodegradability of PAH constituents. PAH analytical data from the 3 runs are not consistent with data for the

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

Treatment Performance Results (cont.)

Table A-2. Oxygen Uptake Rate (mg/L/min) [4]

Day	Run No. 1	Run No. 2	Run No. 3	Loadings
9	0.078	0.067	0.178	Creosote loaded in all 3 runs on Day 1
15	0.131	0.24	0.291	Creosote loaded in Run Nos. 2 and 3 on Day 14; also, soil loaded in Run No. 3 on Day 14
19	0.049	0.202	0.218	No additional loadings between Days 15 and 19

creosote loadings and reloadings. For example, Run No. 1 (the 1% creosote loaded on Day 0, containing 90% PAHs) corresponds with an expected PAH concentration of 9,000 mg/L, while only 855 mg/L of PAHs were measured. However, the data indicate that PAHs are biodegraded using the microbial cultures in this study, and that bioremediation appears to be feasible for creosote-containing soils at Scott Lumber.

Performance Data Quality

The PAH analyses included matrix spike test quality control efforts. [4]

Table A-3. PAH Data [4]

Days/ Comment	PAH Concentrations (mg/L)												
	Acenaphthene	Fluoranthene	Naphthalene	Benzo(a)-anthracenee	Benzo(a)-pyrene	Benzo(b)-fluoranthene	Benzo(k)-fluoranthene	Chrysene	Anthracene	Fluorene	Phenanthrene	Pyrene	TOTAL
Run No. 1													
0	65	134	228	33	13	12	14	24	21	55	164	92	855
7	11	53	BDL	13	BDL	BDL	BDL	9	8	13	50	36	193
14	BDL	65	BDL	16	BDL	BDL	BDL	12	BDL	BDL	6	48	147
21	BDL	75	BDL	18	BDL	BDL	BDL	13	BDL	BDL	BDL	56	162
26	BDL	36	BDL	9	BDL	BDL	BDL	10	BDL	BDL	BDL	32	87
Control Run													
Before	BDL	20	BDL	6	BDL	BDL	BDL	BDL	BDL	BDL	BDL	18	44
5 min	7	49	34	14	BDL	BDL	BDL	11	22	6	20	41	204
15 min	BDL	38	30	11	BDL	BDL	BDL	BDL	BDL	BDL	10	33	122
30 min	7	63	35	19	BDL	BDL	BDL	13	BDL	5	13	53	208
1 hour	8	63	37	19	BDL	BDL	BDL	14	BDL	6	16	53	216
6 hour	9	48	29	20	BDL	BDL	BDL	15	BDL	8	22	43	194
6 hour dup.	7	41	25	17	BDL	BDL	BDL	12	BDL	6	19	36	162
Run No. 2													
0	75	322	208	80	33	30	33	62	35	65	192	234	1,369
7	19	173	BDL	40	16	14	17	29	19	19	87	120	553
14 before	BDL	167	BDL	45	20	18	20	34	BDL	BDL	BDL	118	442
14 after	15	134	79	33	14	12	14	23	11	26	BDL	93	454
26 before	6	130	BDL	31	16	13	16	34	BDL	BDL	6	94	346
26 after	19	131	100	28	13	11	14	27	BDL	13	31	95	482
39	18	288	BDL	63	20	26	27	67	BDL	BDL	31	246	794
39 froth	13	229	BDL	51	23	21	24	53	BDL	BDL	20	189	623

Key:

before: *Before creosote reloading.*
after: *After creosote reloading.*
dup.: *Duplicate analysis of previous sample.*
froth: *Analysis of froth above bioreactor medium.*
BDL: Below the detection limit (detection limit ranged from 5 to 20 ppm, depending on PAH constituent).
**Sample extraction difficulties.*

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

Table A-3 (cont.). PAH Data [4]

Days/ Comment	PAH Concentrations (mg/L)													
	Acenaphthene	Fluoranthene	Naphthalene	Benzo(a)-anthracene	Benzo(a)-pyrene	Benzo(b)-fluoranthene	Benzo(k)-fluoranthene	Chrysene	Anthracene	Fluorene	Phenanthrene	Pyrene	TOTAL
Run No. 3													
0	510	1,020	1,910	269	105	94	109	224	BDL	467	1,610	706	7,024
7	8	262	67	30	28	30	56	BDL	BDL	BDL	BDL	193	674
14 before	BDL	100	BDL	39	23	22	24	43	BDL	BDL	BDL	146	397
14 after	35	172	163	64	36	35	36	65	16	30	101	217	970
14 dup.	30	135	157	40	22	20	22	41	13	26	82	164	588
26 before	BDL	113	BDL	23	14	12	16	33	BDL	BDL	BDL	113	324
26 after	19	131	100	28	13	11	14	27	BDL	13	31	95	482
39	*	*	*	*	*	*	*	*	*	*	*	137	137
39 dup.	*	*	*	*	*	*	*	*	*	*	*	146	146
39 froth	*	*	*	*	*	*	*	*	*	*	*	129	129

Key:
before: Before creosote reloading.
after: After creosote reloading.
dup.: Duplicate analysis of previous sample.
froth: Analysis of froth above bioreactor medium.
BDL: Below the detection limit (detection limit ranged from 5 to 20 ppm, depending on PAH constituent).
**Sample extraction difficulties.*

Observations and Lessons Learned

Performance Observations and Lessons Learned

- A microbial culture capable of degrading PAHs was grown during this study, as shown by data for oxygen uptake rate and VSS.
- Soils from the Scott Lumber site were shown to be not toxic to the microbial community.
- While the treatability study did not establish the relative biodegradability of PAH constituents, the study showed that PAHs are biodegraded using the microbial cultures in this study and that bioremediation appears feasible for creosote-containing soils at Scott Lumber.
- The treatment vendor indicated that results for DS, SOC, and TOC analyses were inconclusive with respect to microbial activity in the 3 runs.

Other Observations and Lessons Learned

- This technology was selected as the full-scale remedy and successfully implemented at the Scott Lumber Company site. The full-scale treatment application met the established cleanup levels.

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

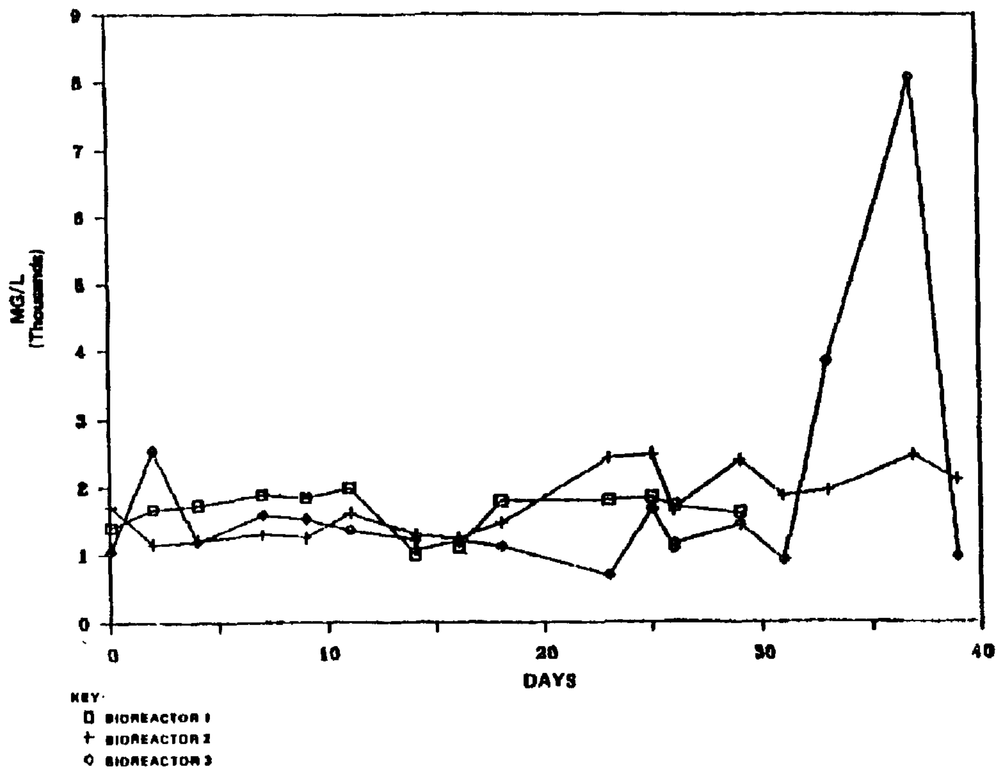


Figure A-1. Dissolved Solids Data [4]

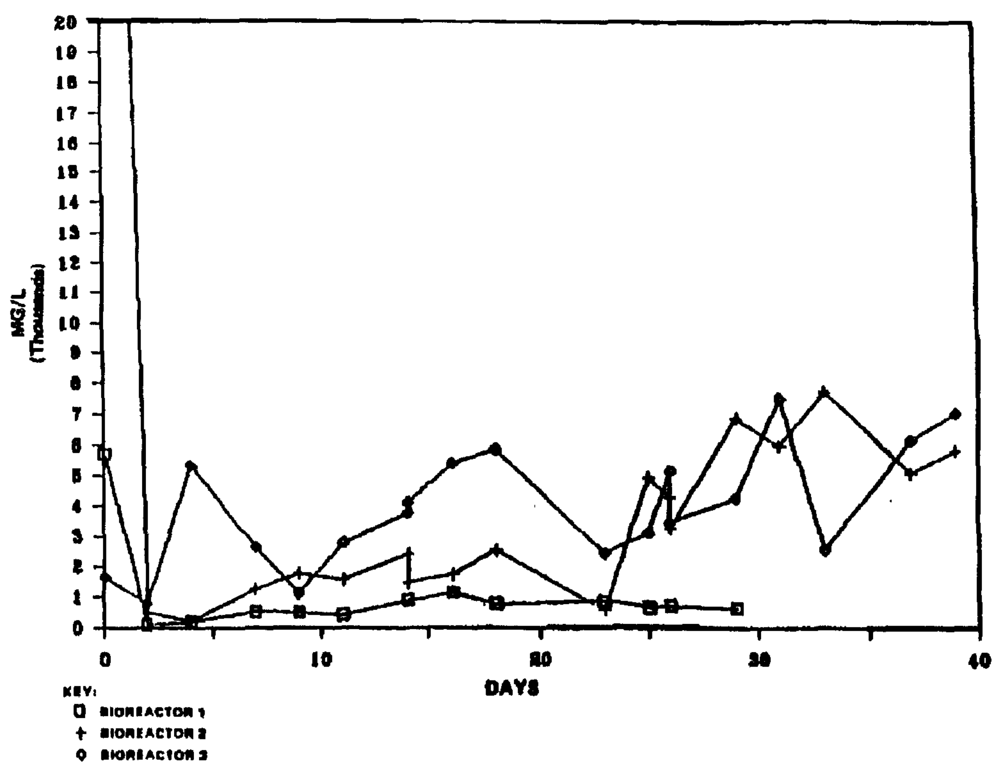


Figure A-2. Volatile Suspended Solids Data [4]

APPENDIX A—TREATABILITY STUDY RESULTS (CONT.)

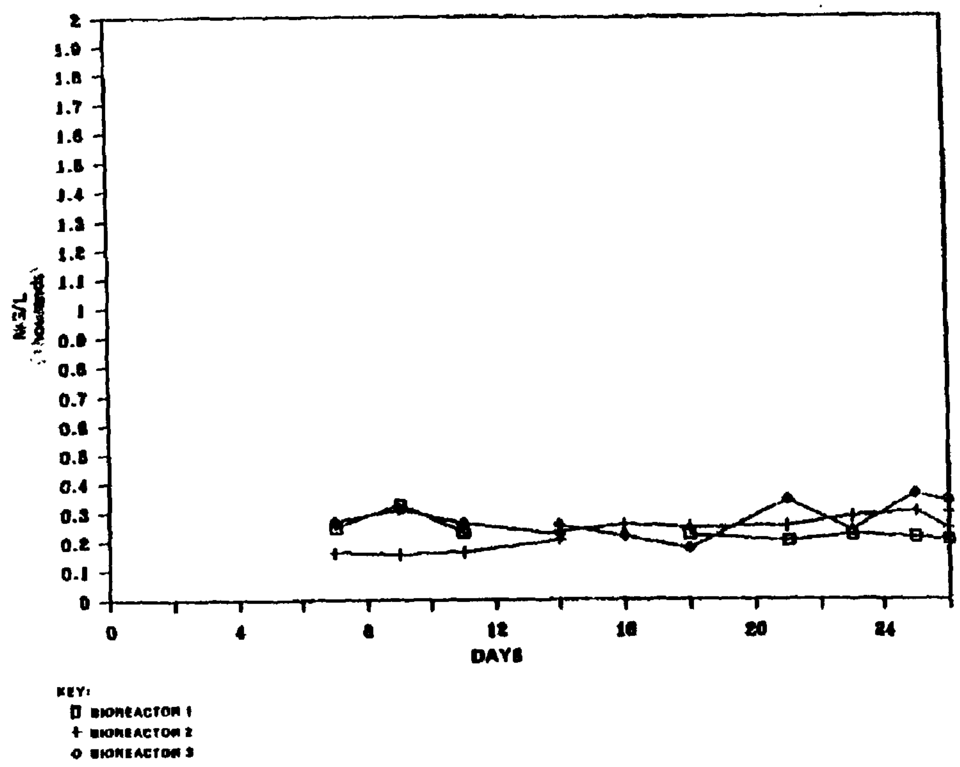


Figure A-3. Soluble Organic Carbon Data [4]

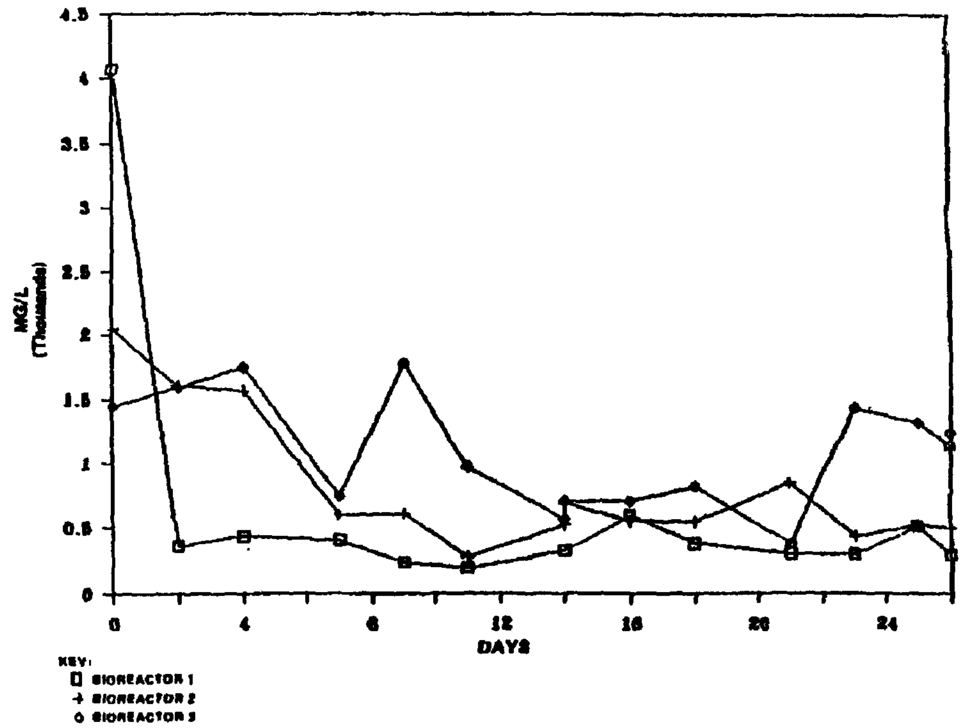


Figure A-4. Total Organic Carbon Data [4]

APPENDIX B—PAH ANALYTICAL RESULTS FOR LIFT ONE

PAH Analytical Results for Lift One [6]
(ug/kg)

		SUBPLOT F QUADRANTS						
Date	**Constituent**	**North**	**North Duplicate**	**South**	**South Duplicate**	**East**	**East Duplicate**	**Average**
04/19/90	NAPHTHALENE	6600 UV	6600 UV	8300 V	110000 V	6500 UV	12000 V	25000
04/19/90	ACENAPHTHYLENE	12000 UV	12000 UV	12000 UV	24000 UV	12000 UV	12000 UV	14000
04/19/90	ACENAPHTHENE	27000 V	12000 V	8700 V	12000 UV	24000 V	23000 V	17783
04/19/90	FLUORENE	15000 V	9100 V	10000 V	110000 V	17000 V	20000 V	30183
04/19/90	PHENANTHRENE	31000 V	26000 V	25000 V	210000 V	40000 V	56000 V	64667
04/19/90	ANTHRACENE	150000 V	36000 V	39000 V	93000 V	55000 V	50000 V	70500
04/19/90	FLUORANTHENE	81000 V	57000 V	54000 V	230000 V	92000 V	88000 V	100333
04/19/90	PYRENE	130000 V	60000 V	58000 JV	150000 V	72000 V	73000 V	90500
04/19/90	ANTHRACENE, BENZO(A)	22000 V	12000 V	11000 V	52000 V	23000 V	21000 V	23500
04/19/90	CHRYSENE	39000 V	22000 V	24000 V	68000 V	40000 V	40000 V	38833
04/19/90	FLUORANTHENE, BENZO(B)	19000 V	11000 V	10000 V	33000 V	19000 V	16000 V	18000
04/19/90	FLUORANTHENE, BENZO(K)	15000 V	8300 V	7900 V	26000 V	15000 V	12000 V	14033
04/19/90	PYRENE, BENZO(A)	16000 V	9200 V	8700 V	34000 V	16000 V	14000 V	16317
04/19/90	PYRENE, INDENO(1,2,3-CD)	18000 V	9400 V	4000 V	48000 V	18000 V	15000 V	18733
04/19/90	ANTHRACENE, DIBENZO(A,H)	2600 V	1900 V	1500 UV	7600 V	1500 V	1500 UV	2767
04/19/90	PERYLENE, BENZO(G,H,I)	14000 V	7400 V	7100 V	30000 V	14000 V	12000 V	14083
04/19/90	**TOTAL PAHs**	**598200**	**299900**	**289200**	**1237600**	**465000**	**465500**	**559233**
05/31/90	NAPHTHALENE	N/A	N/A	N/A	3700 JV	18000 V	11000 V	10900
05/31/90	ACENAPHTHYLENE	N/A	N/A	N/A	1000 UV	2300 V	2600 V	1967
05/31/90	ACENAPHTHENE	N/A	N/A	N/A	11000 V	27000 V	25000 V	21000
05/31/90	FLUORENE	N/A	N/A	N/A	18000 JV	38000 V	38000 V	31333
05/31/90	PHENANTHRENE	N/A	N/A	N/A	59000 JV	100000 V	100000 V	86333
05/31/90	ANTHRACENE	N/A	N/A	N/A	75000 JV	120000 V	140000 V	111667
05/31/90	FLUORANTHENE	N/A	N/A	N/A	66000 JV	90000 V	94000 V	83333
05/31/90	PYRENE	N/A	N/A	N/A	39000 JV	56000 V	58000 V	51000
05/31/90	ANTHRACENE, BENZO(A)	N/A	N/A	N/A	20000 V	28000 V	29000 V	25667
05/31/90	CHRYSENE	40000 V	49000 V	51000 V	24000 V	31000 V	34000 V	38167
05/31/90	FLUORANTHENE, BENZO(B)	24000 V	24000 V	24000 V	14000 V	17000 V	20000	20500
05/31/90	FLUORANTHENE, BENZO(K)	24000 V	24000 V	24000 V	14000 V	17000 V	29999 V	20500
05/31/90	PYRENE, BENZO(A)	23000 V	24000 V	24000 V	12000 V	16000 V	19000 V	19667

APPENDIX B—PAH ANALYTICAL RESULTS FOR LIFT ONE (CONT.)

PAH Analytical Results for Lift One (Continued)
(ug/kg)

		SUBPLOT F QUADRANTS						
Date	**Constituent**	**North**	**North Duplicate**	**South**	**South Duplicate**	**East**	**East Duplicate**	**Average**
05/31/90	PYRENE, INDENO(1,2,3-CD)	11000 V	12000 V	11000 V	6100 V	7100 V	8100 V	9217
05/31/90	ANTHRACENE, DIBENZO(A,H)	1000 UV	3100 V	1000 UV	1000 UV	1000 UV	1000 UV	1350
05/31/90	PERYLENE, BENZO(G,H,I)	8300 V	9200 V	8300 V	4700 V	5800 V	6800 V	7183
05/31/90	**TOTAL PAHs**	**131300**	**145300**	**143300**	**368500**	**574200**	**606500**	**539783**
06/14/90	NAPHTHALENE	13000 V	16000 V	3800 V	7000 V	2500 V	3900 V	7700
06/14/90	ACENAPHTHYLENE	2500 V	1800 V	1400 V	1800 V	1600 V	1700 V	1800
06/14/90	ACENAPHTHENE	11000 V	5300 V	3500 V	8400 V	3600 V	4700 V	6083
06/14/90	FLUORENE	18000 V	14000 V	10000 V	14000 V	6600 V	7800 V	11733
06/14/90	PHENANTHRENE	53000 V	35000 V	23000 V	40000 V	24000 V	24000 V	33167
06/14/90	ANTHRACENE	99000 V	99000 V	87000 V	64000 V	51000 V	59000 V	76500
06/14/90	FLUORANTHENE	110000 V	67000 V	43000 V	62000 V	52000 V	65000 V	66500
06/14/90	PYRENE	54000 V	36000 V	22000 V	29000 V	27000 V	33000 V	33500
06/14/90	ANTHRACENE, BENZO(A)	37000 V	25000 V	15000 V	19000 V	18000 V	22000 V	22667
06/14/90	CHRYSENE	44000 V	30000 V	19000 V	22000 V	23000 V	25000 V	27167
06/14/90	FLUORANTHENE, BENZO(B)	1000 UV	1000 UV	13000 V	15000 V	15000 V	18000 V	10500
06/14/90	FLUORANTHENE, BENZO(K)	1000 UV	1000 UV	13000 V	15000 V	14000 V	18000 V	10333
06/14/90	PYRENE, BENZO(A)	23000 V	18000 V	12000 V	15000 V	14000 V	16000 V	16333
06/14/90	PYRENE, INDENO(1,2,3-CD)	14000 V	12000 V	7800 V	9100 V	9000 V	10000 V	10317
06/14/90	ANTHRACENE, DIBENZO(A,H)	7000 V	4100 V	2700 V	3400 V	3800 V	3600 V	4100
06/14/90	PERYLENE, BENZO(G,H,I)	12000 V	9600 V	6700 V	7500 V	7600 V	8600 V	8667
06/14/90	**TOTAL PAHs**	**499500**	**374800**	**282900**	**332200**	**272700**	**320300**	**347067**
06/28/90	NAPHTHALENE	1400 V	1900 V	3700 V	3800 V	1900 V	1500 V	2367
06/28/90	ACENAPHTHYLENE	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000
06/28/90	ACENAPHTHENE	1900 V	2200 V	3300 V	3200 V	2600 V	2500 V	2617
06/28/90	FLUORENE	5700 V	5900 V	5500 V	7900 V	6900 V	6500 V	6400
06/28/90	PHENANTHRENE	19000 V	20000 V	20000 V	23000 V	26000 V	33000 V	23500
06/28/90	ANTHRACENE	46000 V	51000 V	41000 V	64000 V	71000 V	47000 V	53333
06/28/90	FLUORANTHENE	25000 V	24000 V	35000 V	22000 V	36000 V	42000 V	30667
06/28/90	PYRENE	35000 V	36000 V	51000 V	31000 V	51000 JV	55000 V	43167
06/28/90	ANTHRACENE, BENZO(A)	20000 V	22000 V	23000 V	18000 V	26000 JV	26000 V	22500

APPENDIX B—PAH ANALYTICAL RESULTS FOR LIFT ONE (CONT.)

PAH Analytical Results for Lift One (Continued)
(ug/kg)

Date	Constituent	SUBPLOT F QUADRANTS North	North Duplicate	South	South Duplicate	East	East Duplicate	Average
06/28/90	CHRYSENE	29000 V	28000 V	31000 V	23000 V	36000 JV	33000 V	30000
06/28/90	FLUORANTHENE, BENZO(B)	16000 V	17000 V	18000 V	15000 V	17000 V	19000 V	17000
06/28/90	FLUORANTHENE, BENZO(K)	16000 V	17000 V	17000 V	14000 V	17000 V	19000 V	16667
06/28/90	PYRENE, BENZO(A)	16000 V	18000 V	19000 V	15000 V	17000 V	19000 V	17333
06/28/90	PYRENE, INDENO(1,2,3-CD)	16000 V	16000 V	16000 UV	14000 V	15000 V	17000 V	15667
06/28/90	ANTHRACENE, DIBENZO(A,H)	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000
06/28/90	PERYLENE, BENZO(G,H,I)	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000
06/28/90	**TOTAL PAHs**	**250000**	**262000**	**286500**	**256900**	**326400**	**323500**	**284217**
07/12/90	NAPHTHALENE	2000 UV	2000 UV	2000 UV	2000 UV	2000 UV	2000 UV	2000
07/12/90	ACENAPHTHYLENE	2000 UV	2000 UV	2000 UV	2000 UV	2000 UV	2000 UV	2000
07/12/90	ACENAPHTHENE	2000 UV	2000 UV	2000 UV	2000 UV	2000 UV	2000 UV	2000
07/12/90	FLUORENE	5800 V	5400 V	2300 V	3600 V	5300 V	2000 UV	4067
07/12/90	PHENANTHRENE	12000 V	10000 V	6900 V	9900 V	16000 V	5700 V	10083
07/12/90	ANTHRACENE	60000 V	45000 V	16000 V	40000 V	73000 V	17000 V	41833
07/12/90	FLUORANTHENE	22000 V	19000 V	19000 V	27000 V	32000 V	42000 V	26833
07/12/90	PYRENE	16000 V	10000 V	11000 V	24000 V	20000 V	37000 V	19667
07/12/90	ANTHRACENE, BENZO(A)	9600 V	10000 V	8300 V	13000 V	14000 V	17000 V	11983
07/12/90	CHRYSENE	13000 V	16000 V	12000 V	20000 V	21000 V	22000 V	17333
07/12/90	FLUORANTHENE, BENZO(B)	11000 V	9000 V	10000 V	11000 V	17000 V	12000 V	11667
07/12/90	FLUORANTHENE, BENZO(K)	11000 V	9000 V	10000 V	11000 V	17000 V	12000 V	11667
07/12/90	PYRENE, BENZO(A)	9100 V	10000 V	8800 V	15000 V	14000 V	16000 V	12150
07/12/90	PYRENE, INDENO(1,2,3-CD)	5800 V	9100 V	5500 V	9200 V	11000 V	10000 V	8433
07/12/90	ANTHRACENE, DIBENZO(A,H)	2000 UV	2600 V	2000 UV	2800 V	2000 UV	2300 V	2283
07/12/90	PERYLENE, BENZO(G,H,I)	4500 V	7000 V	4200 V	7500 V	8400 V	7300 V	6483
07/12/90	**TOTAL PAHs**	**187800**	**168100**	**122000**	**200000**	**256700**	**208300**	**190483**
07/26/90	NAPHTHALENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
07/26/90	ACENAPHTHYLENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
07/26/90	ACENAPHTHENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
07/26/90	FLUORENE	5000 UV	5000 UV	5000 UV	17000 V	5000 UV	5000 UV	7000
07/26/90	PHENANTHRENE	8500 V	8100 V	6000 V	29000 V	11000 V	9000 V	11933

APPENDIX B—PAH ANALYTICAL RESULTS FOR LIFT ONE (CONT.)

PAH Analytical Results for Lift One (Continued)
(ug/kg)

		SUBPLOT F QUADRANTS						
Date	**Constituent**	**North**	**North Duplicate**	**South**	**South Duplicate**	**East**	**East Duplicate**	**Average**
07/26/90	ANTHRACENE	27000 V	27000 V	18000 V	5000 V	36000 V	21000 V	22333
07/26/90	FLUORANTHENE	15000 V	18000 V	14000 V	22000 V	17000 V	28000 V	19000
07/26/90	PYRENE	26000 V	35000 V	21000 V	54000 V	32000 V	51000 V	36500
07/26/90	ANTHRACENE, BENZO(A)	12000 V	14000 V	10000 V	15000 V	12000 V	18000 V	13500
07/26/90	CHRYSENE	19000 V	19000 V	15000 V	27000 V	17000 V	22000 V	19833
07/26/90	FLUORANTHENE, BENZO(B)	10000 V	15000 V	7500 V	17000 V	14000 V	11000 V	12417
07/26/90	FLUORANTHENE, BENZO(K)	10000 V	15000 V	7500 V	17000 V	14000 V	11000 V	12417
07/26/90	PYRENE, BENZO(A)	11000 V	12000 V	9600 V	14000 V	11000 V	14000 V	11933
07/26/90	PYRENE, INDENO(1,2,3-CD)	5000 UV	7600 V	5700 V	7400 V	5600 V	8300 V	6600
07/26/90	ANTHRACENE, DIBENZO(A,H)	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
07/26/90	PERYLENE, BENZO(G,H,I)	5000 UV	7100 V	4800 V	7000 V	5600 V	6600 V	6017
07/26/90	**TOTAL PAHs**	**173500**	**202800**	**144100**	**251400**	**200200**	**224900**	**199483**
08/09/90	NAPHTHALENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
08/09/90	ACENAPHTHYLENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
08/09/90	ACENAPHTHENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
08/09/90	FLUORENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
08/09/90	PHENANTHRENE	5000 UV	9900 V	6500 V	5000 UV	5700 V	8900 V	6833
08/09/90	ANTHRACENE	13000 V	53000 V	33000 V	27000 V	22000 V	41000 V	31500
08/09/90	FLUORANTHENE	9100 V	32000 V	21000 V	13000 V	17000 V	22000 V	19017
08/09/90	PYRENE	9800 V	25000 V	24000 V	14000 V	18000 V	23000 V	18967
08/09/90	ANTHRACENE, BENZO(A)	5500 V	16000 V	12000 V	9400 V	11000 V	13000 V	11150
08/09/90	CHRYSENE	10000 V	33000 V	22000 V	19000 V	20000 V	22000 V	21000
08/09/90	FLUORANTHENE, BENZO(B)	7800 V	21000 V	20000 V	17000 V	29000 V	18000 V	18800
08/09/90	FLUORANTHENE, BENZO(K)	7500 V	15000 V	13000 V	13000 V	13000 V	15000 V	12750
08/09/90	PYRENE, BENZO(A)	5400 V	15000 V	14000 V	12000 V	13000 V	14000 V	12233
08/09/90	PYRENE, INDENO(1,2,3-CD)	5000 UV	10000 V	8000 V	8300 V	7900 V	9400 V	8100
08/09/90	ANTHRACENE, DIBENZO(A,H)	5000 UV	8300 V	5000 UV	5000 UV	5000 UV	5000 UV	5550
08/09/90	PERYLENE, BENZO(G,H,I)	5000 UV	5000 UV	7000 V	7000 V	6600 V	8100 V	6450
08/09/90	**TOTAL PAHs**	**108100**	**263200**	**205500**	**169700**	**188200**	**219400**	**192350**
08/23/90	NAPHTHALENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000

APPENDIX B—PAH ANALYTICAL RESULTS FOR LIFT ONE (CONT.)

PAH Analytical Results for Lift One (Continued)
(ug/kg)

		SUBPLOT F QUADRANTS						
Date	**Constituent**	**North**	**North Duplicate**	**South**	**South Duplicate**	**East**	**East Duplicate**	**Average**
08/23/90	ACENAPHTHYLENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
08/23/90	ACENAPHTHENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
08/23/90	FLUORENE	5000 UV	5000 UV	5000 UV	5000 UV	5100 V	5000 UV	5017
08/23/90	PHENANTHRENE	5500 V	11000 V	5000 UV	5400 V	13000 V	6100 V	7667
08/23/90	ANTHRACENE	27000 V	46000 V	21000 V	22000 V	50000 V	44000 V	35000
08/23/90	FLUORANTHENE	15000 V	20000 V	20000 V	23000 V	15000 V	13000 V	17667
08/23/90	PYRENE	13000 V	17000 V	20000 V	21000 V	14000 V	13000 V	16333
08/23/90	ANTHRACENE, BENZO(A)	5000 UV	5000 UV	10000 V	12000 V	9000 V	8500 V	8250
08/23/90	CHRYSENE	20000 V	20000 V	19000 V	20000 V	17000 V	15000 V	18500
08/23/90	FLUORANTHENE, BENZO(B)	30000 V	30000 V	30000 V	30000 V	27000 V	26000 V	28833
08/23/90	FLUORANTHENE, BENZO(K)	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
08/23/90	PYRENE, BENZO(A)	12000 V	13000 V	12000 V	13000 V	12000 V	11000 V	12167
08/23/90	PYRENE, INDENO(1,2,3-CD)	8000 V	8000 V	7500 V	7700 V	6900 V	7000 V	7517
08/23/90	ANTHRACENE, DIBENZO(A,H)	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
08/23/90	PERYLENE, BENZO(G,H,I)	8000 V	7000 V	7500 V	7100 V	6800 V	6800 V	7200
08/23/90	**TOTAL PAHs**	**173500**	**207000**	**182000**	**191200**	**200800**	**180400**	**189150**
09/06/90	NAPHTHALENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
09/06/90	ACENAPHTHYLENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
09/06/90	ACENAPHTHENE	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
09/06/90	FLUORENE	5000 UV	5000 UV	5000 UV	7000 V	5000 UV	5000 UV	5333
09/06/90	PHENANTHRENE	15000 V	6000 V	5000 UV	13000 V	5000 UV	7000 V	8500
09/06/90	ANTHRACENE	75000 V	29000 V	32000 V	74000 V	27000 V	38000 V	45833
09/06/90	FLUORANTHENE	20000 V	15000 V	11000 V	13000 V	14000 V	11000 V	14000
09/06/90	PYRENE	18000 V	15000 V	12000 V	13000 V	16000 V	13000 V	14500
09/06/90	ANTHRACENE, BENZO(A)	14000 V	12000 V	10000 V	10000 V	12000 V	11000 V	11500
09/06/90	CHRYSENE	20000 V	17000 V	14000 V	15000 V	20000 V	17000 V	17167
09/06/90	FLUORANTHENE, BENZO(B)	18000 V	16000 V	13000 V	16000 V	16000 V	15000 V	15667
09/06/90	FLUORANTHENE, BENZO(K)	14000 V	13000 V	11000 V	10000 V	15000 V	14000 V	12833
09/06/90	PYRENE, BENZO(A)	14000 V	13000 V	11000 V	9000 V	13000 V	12000 V	12000
09/06/90	PYRENE, INDENO(1,2,3-CD)	9000 V	8000 V	6000 V	6000 V	5000 UV	6000 V	6667

APPENDIX B—PAH ANALYTICAL RESULTS FOR LIFT ONE (CONT.)

PAH Analytical Results for Lift One (Continued)
(ug/kg)

		SUBPLOT F QUADRANTS						
Date	**Constituent**	**North**	**North Duplicate**	**South**	**South Duplicate**	**East**	**East Duplicate**	**Average**
09/06/90	ANTHRACENE, DIBENZO(A,H)	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000 UV	5000
09/06/90	PERYLENE, BENZO(G,H,I)	9000 V	8000 V	5000 UV	5000 UV	5000 UV	5000 UV	6167
09/06/90	**TOTAL PAHs**	**251000**	**177000**	**155000**	**211000**	**173000**	**174000**	**190167**
09/20/90	NAPHTHALENE	1300 V	1100 V	1400 V	1500 V	1900 V	2600 V	1633
09/20/90	ACENAPHTHYLENE	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000
09/20/90	ACENAPHTHENE	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000
09/20/90	FLUORENE	2400 V	1800 V	2600 V	2200 V	3200 V	4400 V	2767
09/20/90	PHENANTHRENE	7800 V	5500 V	7100 V	7100 V	7700 V	9000 V	7367
09/20/90	ANTHRACENE	25000 V	21000 V	28000 V	25000 V	34000 V	51000 V	30667
09/20/90	FLUORANTHENE	9000 V	6900 V	7700 V	8400 V	8400 V	7000 V	7900
09/20/90	PYRENE	29000 V	19000 V	20000 V	26000 V	26000 V	18000 V	23000
09/20/90	ANTHRACENE, BENZO(A)	11000 V	8600 V	8800 V	9600 V	9000 V	8300 V	9217
09/20/90	CHRYSENE	18000 V	13000 V	14000 V	16000 V	15000 V	14000 V	15000
09/20/90	FLUORANTHENE, BENZO(B)	16000 V	14000 V	20000 V	8200 V	13000 V	14000 V	14200
09/20/90	FLUORANTHENE, BENZO(K)	12000 V	7600 V	8000 V	12000 V	11000 V	7000 V	9600
09/20/90	PYRENE, BENZO(A)	14000 V	11000 V	11000 V	12000 V	11000 V	11000 V	11667
09/20/90	PYRENE, INDENO(1,2,3-CD)	12000 V	1000 UV	10000 V	10000 V	1000 UV	1000 UV	5833
09/20/90	ANTHRACENE, DIBENZO(A,H)	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000 UV	1000
09/20/90	PERYLENE, BENZO(G,H,I)	10000 V	7700 V	8300 V	8600 V	8000 V	8000 V	8433
09/20/90	**TOTAL PAHs**	**170500**	**121200**	**149900**	**149600**	**152200**	**158300**	**150283**
10/05/90	NAPHTHALENE	2500 UV	2500 UV	2500 UV	2500 UV	2500 UV	2500 UV	2500
10/05/90	ACENAPHTHYLENE	2500 UV	2500 UV	2500 UV	2500 UV	2500 UV	2500 UV	2500
10/05/90	ACENAPHTHENE	2500 UV	2500 UV	2500 UV	2500 UV	2500 UV	2500 UV	2500
10/05/90	FLUORENE	3000 V	2500 UV	2500 UV	2500 UV	2700 V	2500 UV	2617
10/05/90	PHENANTHRENE	6500 V	4700 V	6100 V	4200 V	6400 V	7300 V	5867
10/05/90	ANTHRACENE	37000 V	24000 V	26000 V	25000 V	32000 V	28000 V	28667
10/05/90	FLUORANTHENE	10000 V	13000 V	21000 V	8200 V	11000 V	13000 V	12700
10/05/90	PYRENE	10000 V	14000 V	22000 V	11000 V	12000 V	12000 V	13500
10/05/90	ANTHRACENE, BENZO(A)	7400 V	8100 V	11000 V	7400 V	7800 V	8000 V	8283
10/05/90	CHRYSENE	12000 V	12000 V	16000 V	14000 V	13000 V	13000 V	13333

APPENDIX B—PAH ANALYTICAL RESULTS FOR LIFT ONE (CONT.)

PAH Analytical Results for Lift One (Continued)
(ug/kg)

		SUBPLOT F QUADRANTS						
Date	Constituent	North	North Duplicate	South	South Duplicate	East	East Duplicate	Average
10/05/90	FLUORANTHENE, BENZO(B)	12000 V	12000 V	17000 V	14000 V	10000 V	13000 V	13000
10/05/90	FLUORANTHENE, BENZO(K)	9000 V	11000 V	12000 V	8200 V	6100 V	9800 V	9350
10/05/90	PYRENE, BENZO(A)	9400 V	1000 V	13000 V	10000 V	8900 V	9600 V	8650
10/05/90	PYRENE, INDENO(1,2,3-CD)	8100 V	7200 V	10000 V	9000 V	7800 V	9000 V	8517
10/05/90	ANTHRACENE, DIBENZO(A,H)	2600 V	2500 UV	3300 V	2500 UV	2500 UV	2500 UV	2650
10/05/90	PERYLENE, BENZO(G,H,I)	6900 V	8500 V	8600 V	6900 V	6500 V	7300 V	7450
10/05/90	**TOTAL PAHs**	**141400**	**128000**	**176000**	**130400**	**134200**	**142500**	**142083**
10/18/90	NAPHTHALENE	2000	1000 U	1000 U	1000 U	1000 U	1000	1167
10/18/90	ACENAPHTHYLENE	1000 U	1000 U	1000 U	1000 U	1000 U	1000 U	1000
10/18/90	ACENAPHTHENE	1000 U	1000 U	1000 U	1000 U	1000 U	1000 U	1000
10/18/90	FLUORENE	4800	1100	1400	1000 U	1000 U	3100	2067
10/18/90	PHENANTHRENE	8200	4400	3300	3300	3800	6700	4950
10/18/90	ANTHRACENE	41000	12000	16000	7800	8200	17000	17000
10/18/90	FLUORANTHENE	6900	11000	5200	8600	8600	14000	9050
10/18/90	PYRENE	5800	8100	4600	6300	6500	9900	6867
10/18/90	ANTHRACENE, BENZO(A)	5300	6200	3600	4200	5000	6200	5083
10/18/90	CHRYSENE	9100	13000	8400	8500	11000	12000	10333
10/18/90	FLUORANTHENE, BENZO(B)	24000	31000	23000	20000	33000	34000	27500
10/18/90	FLUORANTHENE, BENZO(K)	24000	31000	23000	20000	33000	34000	27500
10/18/90	PYRENE, BENZO(A)	8000	9700	7800	6000	8900	8900	8217
10/18/90	PYRENE, INDENO(1,2,3-CD)	5200	9700	5000	3900	7100	6200	6183
10/18/90	ANTHRACENE, DIBENZO(A,H)	1000 U	1000 U	1000 U	1000 U	1000 U	1000 U	1000
10/18/90	PERYLENE, BENZO(G,H,I)	5700	6800	5000	3200	6100	6100	5483
10/18/90	**TOTAL PAHs**	**153000**	**148000**	**110300**	**96800**	**136200**	**162100**	**134400**

Windrow Composting of Explosives Contaminated Soil at Umatilla Army Depot Activity Hermiston, Oregon

Case Study Abstract

Windrow Composting of Explosives Contaminated Soil at Umatilla Army Depot Activity, Hermiston, Oregon

Site Name:
Umatilla Army Depot Activity (UMDA), Explosives Washout Lagoons, CERCLA Soils Operable Unit

Location:
Hermiston, Oregon

Contaminants:
Explosives
- Primary soil contaminants include 2,4,6-trinitrotoluene (TNT); hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX); and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)
- Contaminant levels >100 ppm limited to soils in the first 2 to 4 feet below the surface of the lagoons

Period of Operation:
May 1992 to November 1992

Cleanup Type:
Field Demonstration

Vendor:
Roy F. Weston, Inc.

SIC Code:
9711 (National Security)

Technology:
Composting
- Excavated soil screened and mixed with soil amendments
- Nonaerated and aerated windrows composted for 40 days
- Treated soil mixed with top soil and revegetated, redeposited in excavated area, or landfilled
- Windrows contained contaminated soil (30%), cow manure (21%), alfalfa (18%), sawdust (18%), potatoes (10%), and hen manure (3%)
- Mixed 3 to 7 times per week, temperature 15 to 60°C, oxygen up to 21%, moisture 30 to 40%, pH 5 to 9

Cleanup Authority:
CERCLA

Point of Contact:
Remedial Project Manager
Umatilla Army Depot Activity
Hermiston, OR

Waste Source:
Surface Impoundment/Lagoon

Purpose/Significance of Application:
Field demonstration of windrow composting to biodegrade explosives-contaminated soils.

Type/Quantity of Media Treated:
Soil
- 244 cubic yards (8 windrows, 28 cubic yards each)
- Predominantly Quincy fine sand and Quincy loamy fine sand

Regulatory Requirements/Cleanup Goals:
- Concentrations of explosives in soil to be below 30 ppm; target compounds were TNT and RDX
- Top 5 feet of soil below the lagoons to be excavated, treated, and returned to the excavated area

Results:
- Windrow composting performance after 40-day treatment generally reduced the levels of target explosives to below the cleanup goals
- TNT reduced from 1,600 to 4 ppm (aerated and nonaerated)
- RDX reduced from 1,000 to 7 ppm (aerated) and 2 ppm (nonaerated)
- HMX reduced from 200 to 47 ppm (aerated) and 5 ppm (nonaerated)

Windrow Composting of Explosives Contaminated Soil at Umatilla Army Depot Activity, Hermiston, Oregon (Continued)

Cost Factors:
- No costs were available for the field demonstration

Projected cost for full-scale windrow composting:
- Capital cost for treatment activities - $1,840,000 (including equipment, buildings, structures, mechanical/piping, and electrical)
- Five-year operating cost - $2,000,000 (including power, amendments, fuel, labor, and maintenance)
- Full-scale costs assume 20,000 tons of soil, 5-year project duration, nonaerated windrows, mixed daily, 30% soil loading, 30-day treatment periods, and compliance with RCRA Waste Pile Facility Standards

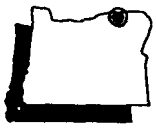
Description:
From approximately 1955 to 1965, the Umatilla Army Depot Activity (UMDA) operated a munitions washout facility in Hermiston, Oregon, where hot water and steam were used to remove explosives from munitions bodies. About 85 million gallons of heavily-contaminated wash water were discharged 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 in a field demonstration at UMDA from May to November 1992 to treat 244 cubic yards of contaminated soil. Nonaerated and aerated windrows were treated for 40 days, using several soil amendments, and tested for residual contamination. TNT was reduced from 1600 to 4 ppm (aerated and nonaerated), RDX reduced from 1000 to 7 ppm (nonaerated) and 2 ppm (aerated), and HMX reduced from 200 to 47 ppm (aerated) and 5 ppm (nonaerated) in the 40 day treatment period. With the exception of HMX (aerated), these levels were below the targeted soil cleanup levels of 30 ppm.

Costs were not available for the field demonstration. The costs for a full-scale application of windrow composting at Umatilla were estimated assuming treatment of 20,000 tons of soil, 5-year project duration, nonaerated windrows, mixed daily, 30% soil loading, 30-day treatment periods, and RCRA Waste Pile facility standards. The capital cost for the full-scale application was estimated as $2,118,000, and the annual operating cost as $527,000.

SITE

Umatilla Depot Activity (UMDA)
Explosives Washout Lagoons
CERCLA Soils Operable Unit
Hermiston, Oregon



TECHNOLOGY APPLICATION

This analysis covers a field demonstration of **windrow composting** to biodegrade explosives contaminated soils. The demonstration was conducted from January 1992 to January 1993 to provide information for a full-scale remedial design.

SITE CHARACTERISTICS

Site History/Release Characteristics

- UMDA is a 20,000 acre facility established in 1941 whose mission has included storage of chemical munitions and containerized chemical agents as well as the disassembly, assembly, packaging and storage of conventional munitions.
- From approximately 1955 to 1965, UMDA operated a munitions washout facility where hot water and steam were used to remove explosives from munition bodies.
- A total of about 85 million gallons of heavily contaminated wash water was discharged to two settling lagoons.
- Surface buildup of explosives was periodically excavated, but underlying soils and ground water became contaminated.
- Based on investigations initiated in the late 70s and accelerated in 1986 through the RCRA program, the lagoons were placed on the NPL in 1987. UMDA is currently in the Base Realignment and Closure (BRAC) program.

Contaminants of Concern

Contaminants of Concern identified in the Risk Assessment are:

Soil:
1,3,5-Trinitrobenzene (TNB)
1,3-Dinitrobenzene (DNB)
2,4,6-Trinitrotoluene (TNT)
2,4-Dinitrotoluene (2,4-DNT)
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)
Nitrobenzene (NB)
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)

Ground water:
same as soil plus
2,6-Dinitrotoluene (2,6-DNT)
N,2,4,6-Tetranitro-N-methylaniline (Tetryl)

Contaminant Properties

Properties of contaminants focused upon during remediation are:

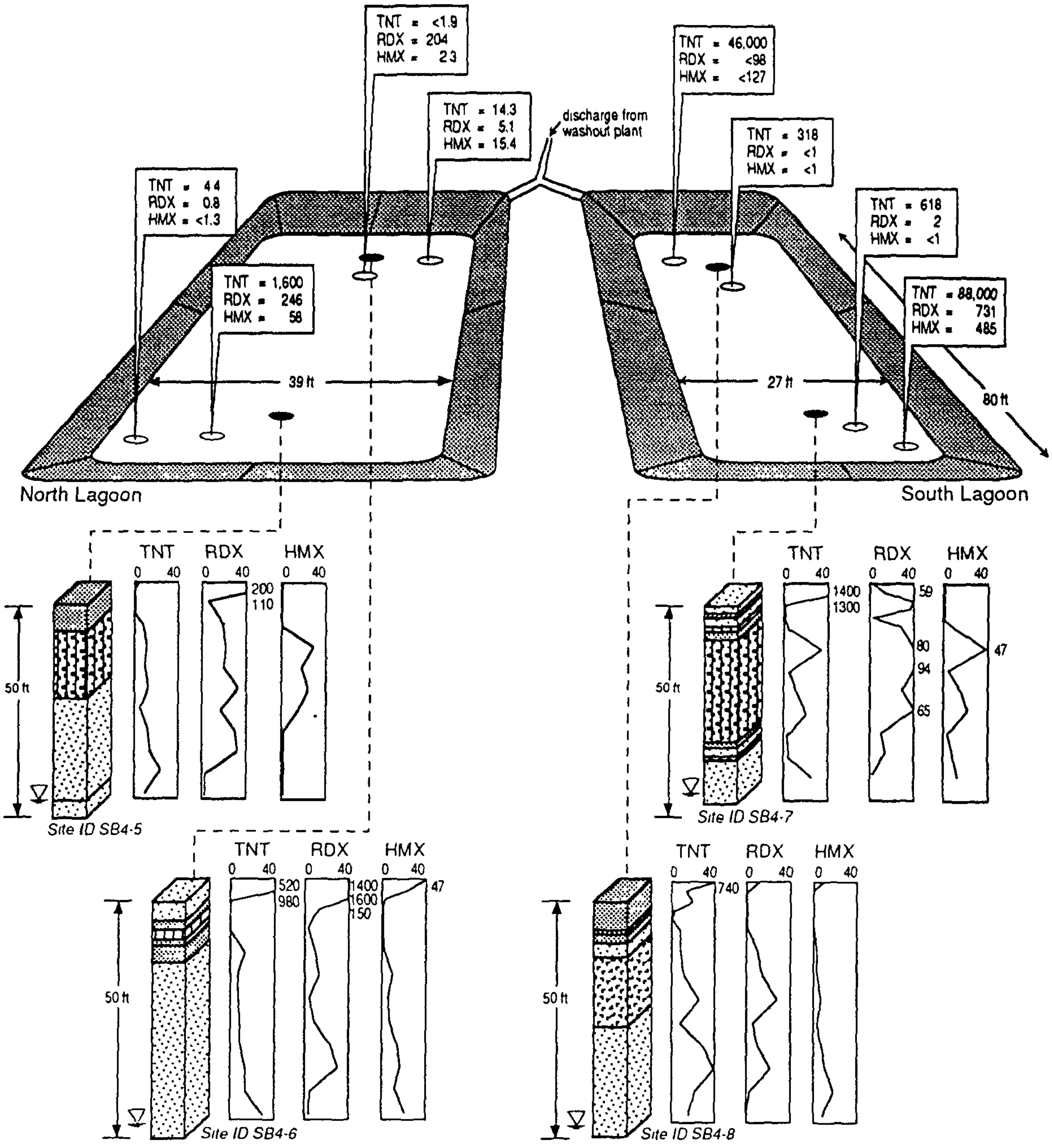
Property at STP*	Units	TNT	RDX	HMX
Empirical Formula	-	$C_7H_5N_3O_6$	$C_3H_6N_6O_6$	$C_4H_8N_8O_8$
Density	g/cm^3	1.65	1.83	1.90
Melting Point	^oC	81	205	286
Vapor Pressure	mmHg	5.51E-6	4.03E-9	3.33E-14
Water Solubility	mg/L	150	60	5
Octanol-Water Partition Coefficient; logKow	-	2.00	0.87	0.26
Site Specific Soil-Water Partition Coefficient; Kd	ml/g	1.00	0.21	0.44

**STP = Standard Temperature and Presure; 1 atm, 25 ^oC*

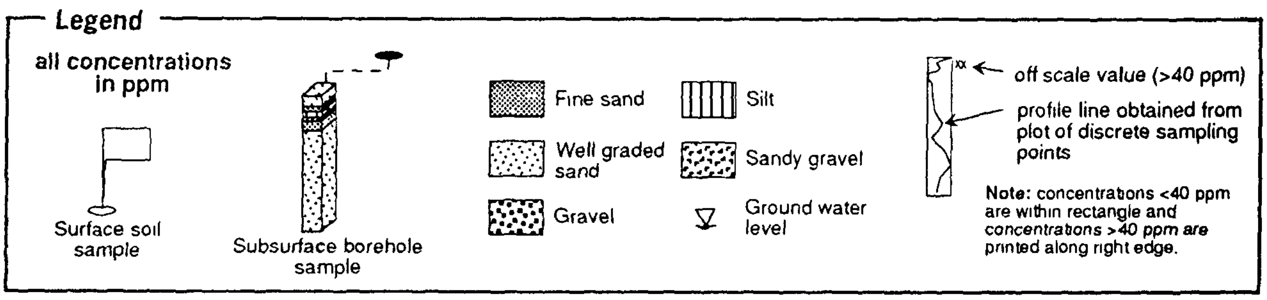
Nature & Extent of Contamination

- Elevated levels (>100 ppm) of contaminants limited to soils in the first 2 to 4 feet below the surface of the lagoons.
- Detectable concentrations found down to the ground water table due to vertical migration in highly permeable soils.
- Contaminant distribution varies versus depth and among borings indicating influence of microlithology.
- Concentrations for all explosives outside the lagoons were significantly lower than beneath the lagoons as lateral migration did not appear significant.
- Little correlation found between soil and ground water contaminant concentrations.

Soil Sampling Results: Contaminant Locations and Geologic Profiles



NOTE: Additional surface and borehole sampling outside of the lagoons revealed significantly lower levels of contamination. Site ID numbers refer to borehole identification numbers used in site documentation.



Site Conditions

- Surrounding region characterized by a semi-arid, cold desert climate
- Surrounding land use is primarily irrigated agriculture.
- The six foot deep lagoons were constructed with relatively permeable gravels
- Soil beneath the lagoons is clean fine sand with gravel in the top 5 to 7 feet and predominantly sand below 25 to 35 feet; sand varies in character; gravel is fine grained with 1/4 to 1/2 inch particles; minor amounts of silt encountered as thin 1 to 24 inch seams.
- Ground water levels vary between 44 to 49 feet below the bottom of the lagoons.

Key Soil Characteristics

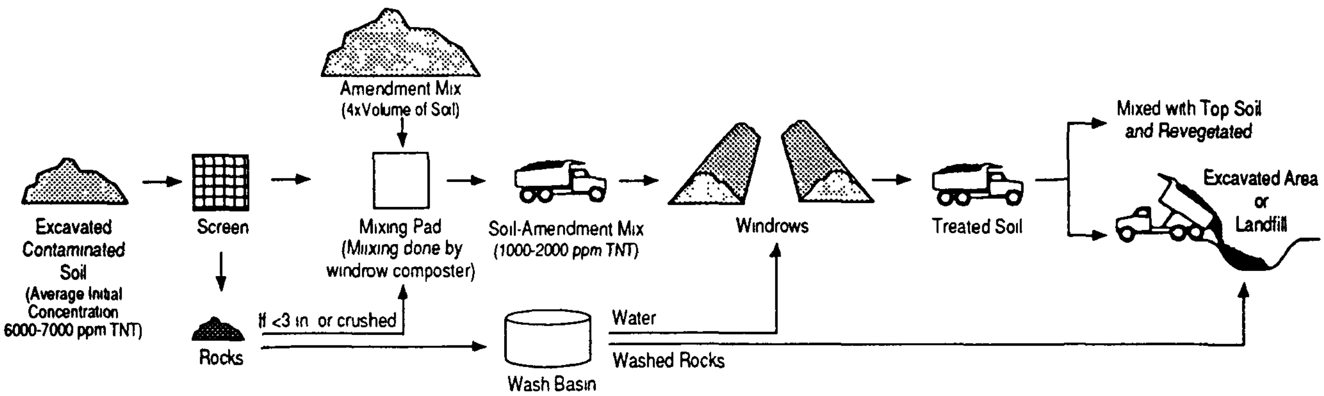
Parameter	Depth 0 ft	4 ft	10 ft	Comment *[all data taken from four soil borings beneath lagoons]*
pH	7.6-8.4	7.9-8.4	8.1-8.3	Relatively uniform and typical of mineral soils in arid regions
Moisture Content [%]	3.5-5.3	4.8-17.5	4.7-16.7	Higher for silt lenses; mean value of 7.2
Total Organic Content [%]	0.9-7.3	1.2-3.6	0.8-2.2	Corresponds with level of explosives contamination; mean value of 2.6

Site soils are predominantly Quincy fine sand and Quincy loamy fine sand:

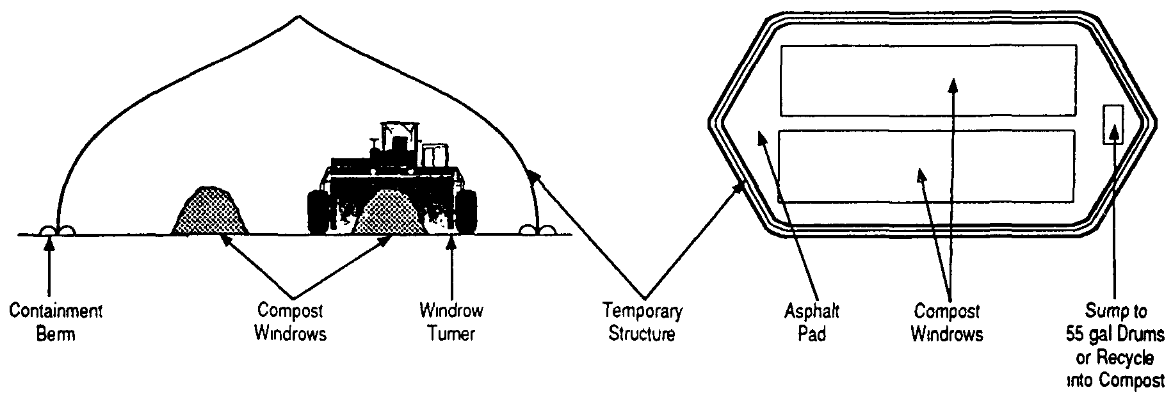
- **Quincy fine sand** is a very deep, excessively drained soil formed in mixed sand. Permeability is rapid and water-holding capacity is low. Effective rooting depth is greater than 5 feet. However, 80 percent of roots are found in the upper 12 inches. Soil pH gradually increases with depth from about neutral to 8.5 at 5 feet. Nearly 100 percent of the upper layer passes the 40 mesh sieve and about 30 percent passes the 200 mesh sieve. Wind erodibility is extremely high if vegetation is removed, which is the case at portions of Umatilla. Organic matter is generally less than 0.5 percent.
- **Quincy loamy fine sand** is very similar but occurs on slightly flatter slopes and has slightly more silt and clay in the upper layer, resulting in a higher water holding capacity

TREATMENT SYSTEM

Overall Process Schematic

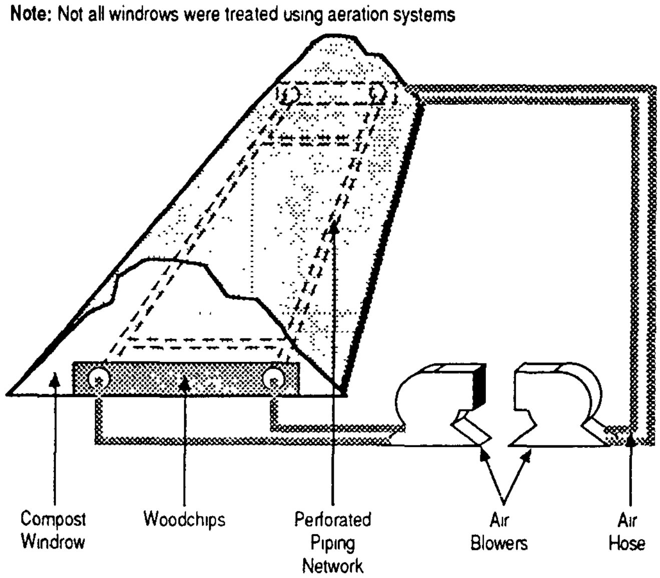


Compost System Close-up



Aerated Windrow

Note: Not all windrows were treated using aeration systems



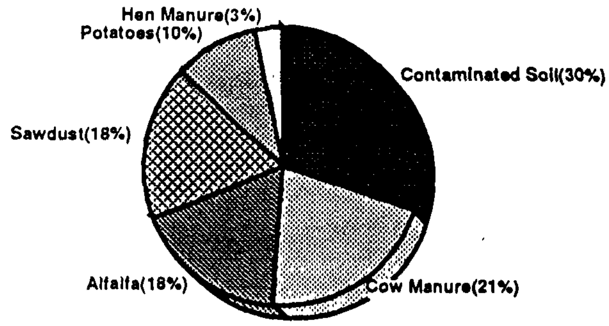
Compost Composition

The compost amendment recipe was developed through bench-scale treatability studies.

Factors taken into consideration included:

- carbon:nitrogen ratio
- moisture content
- homogeneity
- seasonal availability
- total metabolic energy content
- rate of carbon substrate use
- pH
- cost
- texture
- form
- porosity

The recipe utilized in windrows with a 30% soil loading rate was approximately:



Key Monitored Operating Parameters

Parameter	Range of Values*	Method of Control
Mixing Frequency	3 to 7 times/week	Frequency of windrow turner operation
Temperature**	15 to 60°C	*Unaerated Windrows* - No control other than effects of mixing *Aerated Windrows* - Aeration blowers set to cool to set point of 55°C whenever 60°C was exceeded
Oxygen	≈0 to 21% O_2	*Unaerated Windrows* - No control other than effects of mixing *Aerated Windrows* - Aeration blowers set on an operating cycle of 15 minutes off/20 seconds on in addition to temperature control
Moisture	30 to 40%	Garden hose water addition used to maintain a 50 to 80% Water Holding Capacity (WHC) level
pH	5 to 9	Controlled through selection of compost amendment composition

* *Range of values observed during composting of contaminated windrows*
** *Temperature used as primary indicator of composting activity*

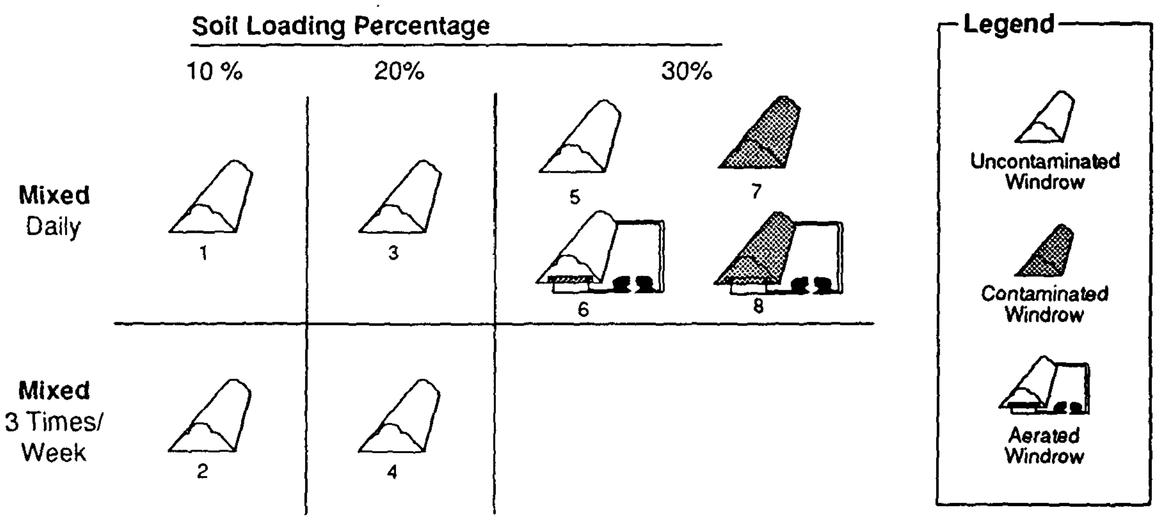
PERFORMANCE

Performance Objectives

- Achieve cleanup goal of 30 ppm TNT and RDX in top 5 feet of lagoon soils..
- Achieve optimum mixing frequency, soil loading rates, and degree of aeration during treatment.
- Determine potential treatment benefits from adding fresh amendment to active compost windrows *(supplementation)* and initiating new windows with active compost from existing windrows *(seeding)*.

Treatment Plan

A total of 6 uncontaminated and 2 contaminated windrows approximately 28 yd³ in size were composted for 40 days either with or without aeration and with varying degrees of mixing and soil loading:



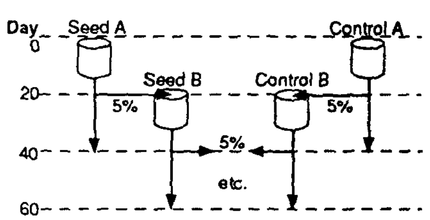
Initial Process Optimization Efforts

Uncontaminated Windrow Treatment

- Successful thermophilic composting observed in windrows with soil loading up to 30%.
- Aeration resulted in temporary overheating and a more rapid, but less prolonged, heating and composting for the blower configuration utilized.
- Windrow temperature increased and interstitial oxygen levels decreased to previous levels quickly (within an hour) following the temporary upset (temperature decrease and oxygen level increase) of mixing ---- Daily mixing frequencies were assumed to be appropriate for future treatments
- Supplementation of active windrows through the addition of fresh amendment (5% by volume) resulted in rapid return of higher temperature levels indicating the potential to exceed the normal period of active thermophilic composting.

Seeding Results

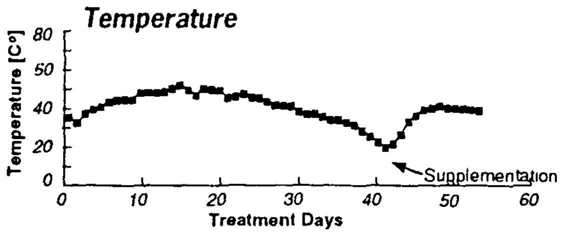
The effects of a 5% recycle from active to initiating piles was conducted in a series of 40 day runs in 50 gallon insulated, aerated, fiberglass tanks:

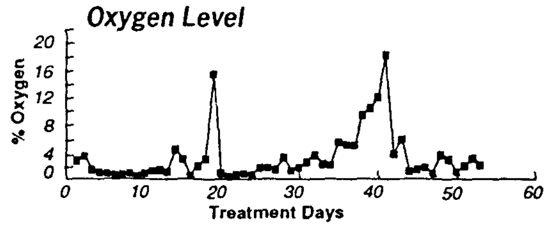


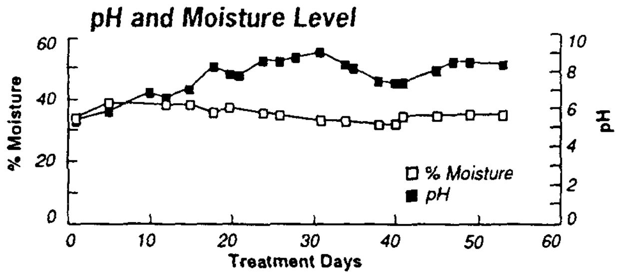
Based upon theoretical principles, the seeding approach should have illustrated some benefits. However, no concrete evidence of benefits was discovered in this study under the conditions tested.

Contaminated Windrow Treatment

Key Measured Parameters

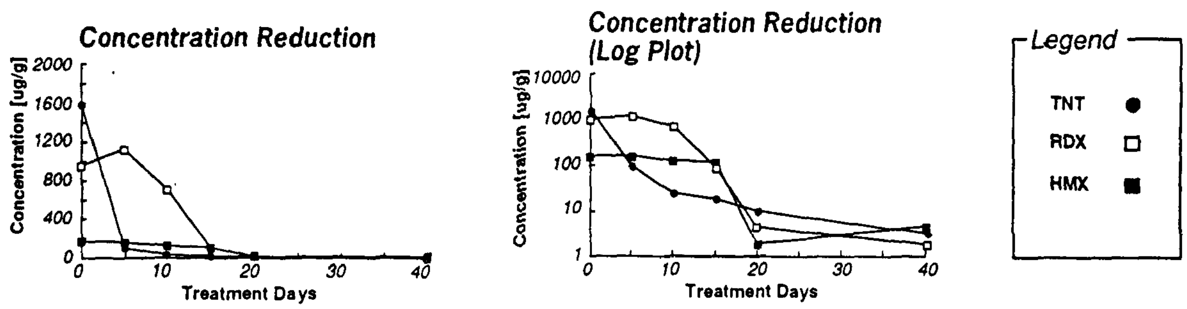






Note: All data provided for nonaerated windrow at times immediately before mixing by windrow turner. Aerated windrow data differed primarily by having oxygen levels in the 10 to 20% range during periods of high composting activity

Contaminant Removal Effectiveness



Aerated versus Nonaerated Windrow Performance

	Percent Removal		Concentration After 40 Day Treatment	
	Aerated	Nonaerated	Aerated	Nonaerated
TNT	99.8%	99.7%	4 ppm	4 ppm
RDX	99.2%	99 8%	7 ppm	2 ppm
HMX	76 6%	96 8%	47 ppm	5 ppm

Testing of Treated Product

- **Explosives Intermediates Analysis** - Likely intermediate products (2,4D-6NT; 4A-2,6DNT; 2,6D-4NT, and 2A-4,6DNT) were shown to be effectively removed (<5 ug/g after 40 days).
- **Clean Closure Leaching Test (CCLT)** - leachable explosives were removed after 40 days to a high degree (>99.6% removal for TNT, >98.6 for RDX, and >97.3 for HMX in the nonaerated windrow).
- **Leachate Toxicity Testing** - complete detoxification observed using ceriodaphnia dubia as a test organism.
- **Extractable Mutagenicity Testing** - toxicity reduction reduced during composting as measured through Ames assay.
- **Oversized Rock Washing** - Preliminary rock washing tests indicated that further development of techniques would be necessary to achieve cleanup criteria However, other investigations have revealed that cleanup criteria can be achieved by composting small (<3 in.) rocks with soil Minor modifications to the windrow composter will be made to implement this method during full-scale remediation at Umatilla

COST

The UMDA windrow composting demonstration summarized in this analysis contained enhanced levels of analytical sampling as well as peripheral investigations. A cost estimate was developed to be representative of full-scale windrow composting at UMDA. The estimate (+30% to -15% accuracy) was based upon cost data from the demonstration and assumed:

- 20,000 tons of soil composted in a
- 5 year total project time with
- unaerated windrows, mixed daily, containing a
- 30% soil loading and composted for
- 30 day treatment periods with
- RCRA Waste Pile facility standards in effect.

Capital Costs

Equipment (Backhoe, Dump Truck, Front-End Loader, Water Pump, Windrow Turner)	$567,000
Site Work	280,000
Buildings/Structures	322,000
Mechanical/Piping	26,000
Electrical	129,000
Construction/Mobilization/Demobilization @ 8%	111,000
Construction Equipment, Consumables @ 5%	69,000
Fees @ 1.5%	20,000
General & Administrative Overhead Costs @ 9 5%	150,000
Contractor Markup and Profit @ 10%	168,000
Contingency @ 15%	276,000
Total	**$2,118,000**

Operating Costs

Power (@ $0.07/Kwhr)	$1,000
Amendments (@ $50/ton)	195,000
Diesel Fuel (@ $1.10/gal)	19,000
Labor (@ $20/hr Operator; $16/hr Technician excluding overhead)	116,000
Off-site Analytics ($220/sample)	21,000
Maintenance	64,000
Contractor Markup & Profit @ 10%	42,000
Contingency @ 15%	69,000
Total Annual Operating Cost	**$527,000**
Total 5-Year Present Worth Operating Cost	**$2,104,000**

Cost/Ton $211

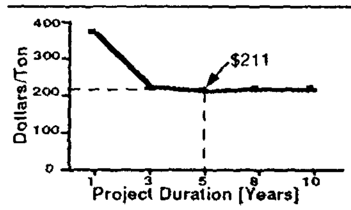
Cost Sensitivities

Effects of Assumption Changes

The $211/ton estimated cost is subject to the following sensitivities:

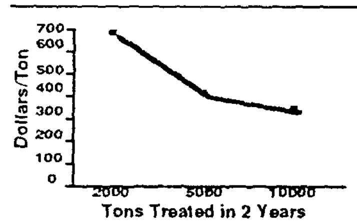
Accounting for salvage value of equipment following treatment	-$12
Elimination of RCRA Waste Pile facility requirements (liner system)	-$5
Elimination of temporary structure in mild climates	-$10 to -15
With a 40% rather than 30% soil loading rate	-$5 to -6
With 20 day rather than 30 day windrow compost periods	-$5
With 3 times/week rather than daily mixing of compost with turner	-$1

Cost versus Cleanup Time



Cost versus Facility Size

(for a 2-year project duration)



REGULATORY/INSTITUTIONAL ISSUES

• **The explosives contaminated** washout water sent to the lagoons is a listed RCRA waste. The compost windrows may **be classified** as waste piles under RCRA and therefore be subject to the facility design requirements of 40 CFR 264 **Subpart** L which include liners and leak detection systems At UMDA these standards were not determined to be **applicable** because of the low reactivity hazard (explosive levels <12%) and low concentrations of 2,4-DNT (a listed RCRA waste), however, EPA Regional Administrators may make alternative determinations at other sites.

• An Army Explosives Hazard Review must be performed for work involving explosives. The hazard review of the **compost turner** determined that soils containing greater than 10% explosives by weight or chunks of explosives greater than 1 inch in diameter must be avoided.

• **Windrow composting was the technology** selected for overall clean-up of the CERCLA site in the Record of **Decision. It was the preferred** alternative to incineration and other composting schemes. The rural local community **preferred composting** not only because of apprehensions about incineration but also for the economic benefits the **purchase** of amendment materials would have for local farmers.

• Level C personal protective equipment was used for handling contaminated soils.

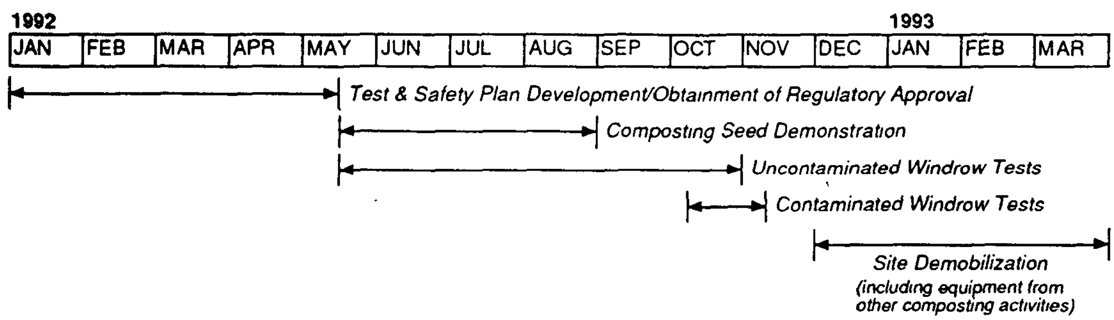
Cleanup Criteria

• Concentrations of explosives in soil must be below 30 ppm (TNT and RDX listed as target compounds).

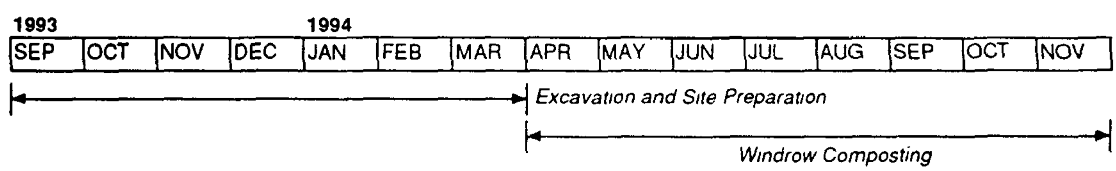
• The top five feet of soil below the lagoons is to be excavated, treated, and returned to the excavated area.

SCHEDULE

For Demonstration Activities at UMDA



Projection for Full-Scale Cleanup at UMDA



LESSONS LEARNED

Key Operating Parameters

- **Amendment composition** affects the biodegradation rate of explosives
- **Temperatures** appropriate for thermophilic organisms (50 to 60°C) enhance biodegradation
- **Mixing** with a windrow turner leads to a more rapid and extensive degradation.
- **Moisture content** should remain near 60%of the Water Holding Capacity.
- **Aeration** of windrows produced higher operating temperatures and reduced odor, however, the nonaerated windrows exhibited equal, or better, removal of TNT, RDX, and HMX.
- A **soil loading** rate of up to 30% soil in the soil-amendment mix produced satisfactory results.
- A **treatment period** of 40 days was sufficient to remove greater than 99% of TNT and RDX and leave residual levels of contamination less than 30 ppm A composting period of 30 days was determined to be adequate for future composting at UMDA
- **Oxygen** depletion in the unaerated windrows was found to occur soon after mixing (within an hour) and a daily turning frequency was adopted for future treatment.
- **Seeding** the initial mix of aerated static pile reactor compost piles with active compost from ongoing piles did not reveal any clear benefits under the conditions studies.
- **Supplementation** of fresh amendment to active compost windrows illustrated the potential to exceed the normal period of active thermophilic composting

Implementation Considerations

- During composting inside the temporary structure, **release of water** vapor from the compost during turning reduced visibility Accumulations of ammonia were also noted. Additional exhaust fans, personal protective equipment and modified operating procedures were used as remedial measures Full-scale ventilation requirements should be evaluated for future applications
- Additional effort was required to maintain the shape and configuration of the windrows. A small front end loader was found to be suitable for this purpose **Maintenance of the windrows** was further complicated for windrows which had aeration systems.
- **Water supply** requirements must be considered in advance. Substantial quantities of water may be required to replace moisture lost during the composting process and to maintain adequate moisture levels Several thousand gallons of water were used per windrow at UMDA
- A **commercially available windrow turner** performed well mechanically and provided good results in composting operations Some modifications may be useful to optimize performance such as variable mixer speeds, exhaust filtration, and the addition of deflectors to minimize the potential for projectiles such as small stone to be thrown during turning
- **Field instrumentation** employed was suitable for monitoring the composting process Less intensive monitoring than was employed in this demonstration would be more appropriate for future applications
- Improvements in **compost sample preparation and analysis protocols** would be beneficial. Field analytical methods for explosives in compost would be useful in process monitoring, with laboratory analyses used for confirmation of cleanup criteria. Modifying the compost sample preparation procedure to minimize drying time would speed operations.
- The windrow composting treatment was successfully conducted under a wide range of **ambient temperatures**. Thermophilic conditions were attained during summer months when daytime highs were well above 100°F, as well as during late autumn when nighttime lows dropped below freezing. From these observations, it appears that with proper containment within an enclosure and with slight adjustments to turning frequency to control heat losses from the material, windrow composting can be implemented year round

Technology Limitations

• Although detailed projections of costs have been made based upon the results of demonstration activities at UMDA, there is a **lack of cost data** from full-scale completed remediations.

• The **cost of the technology is sensitive** to the availability and cost of amendment material, cleanup criteria for a given site, and the treatment facility standards deemed applicable to the composting operation.

• The presence of other contaminants such as **metals may preclude the use of the technology** for some sites with explosives-contaminated soils.

• **Areas for further progress** include efforts to increase compost soil loading percentages, decrease compost cycle times, and improve methods to treat oversized rocks screened from the compost windrows.

Future Technology Selection Considerations

• The **treatment at UMDA built upon earlier results** from studies which illustrated the susceptibility of explosives to microbial degradation, the effectiveness of mechanically agitated in-vessel and aerated static pile composting systems, and the influence of process parameters such as soil loading percentage and compost amendment composition

• The **treatment at UMDA further demonstrated** that windrow composting of explosives contaminated soil:

+ will effectively **remove** both **explosives** (TNT, RDX, and HMX) and selected TNT intermediates,

+ will **reduce toxicity** to a high degree,

+ is relatively **simple** to implement and operate, and

+ is **cost effective** in relation to alternative treatments.

ANALYSIS PREPARATION

This analysis was prepared by

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SOURCES

Major Sources For Each Section

Site Characteristics:	Source #s (from list below) 5,6,8 and 9
Treatment System:	Source #s 1,2 and 7
Performance:	Source #s 1 and 2
Cost:	Source # 1
Regulatory/Institutional Issues:	Source #s 1,2,5,9,12 and personal communication with Capt. Kevin Keehan, U.S. Army Environmental Center (410) 671-1278.
Schedule:	Personal communication with Capt. Timothy O'Rourke, U.S. Army Environmental Center, (410) 671-1580.
Lessons Learned:	Source #s 1,2,5,7, 9, 11, 12 and personal communications with Capt. Keehan.

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18. *Engineering and Development Support of General Decon Technology for the U S. Army's Installation Restoration Program, Task 11: Composting of Explosives*, prepared for USATHAMA, prepared by Atlantic Research Corporation, September 1982.

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