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Technology Evaluation Report

Chemfix Technologies, Inc. Solidification/Stabilization Process Clackamas, Oregon

Volume I

SITE

SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/5-89/011a
September 1990

TECHNOLOGY EVALUATION REPORT
CHEMFIX TECHNOLOGIES, INC.
SOLIDIFICATION/STABILIZATION PROCESS
CLACKAMAS, OREGON

VOLUME I

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NOTICE

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FOREWORD

The Superfund Innovative Technology Evaluation (SITE) program was authorized in the 1986 Superfund amendments. The program is a joint effort between EPA's Office of Research and Development (ORD) and Office of Solid Waste and Emergency Response (OSWER). The purpose of the program is to assist the development of hazardous waste treatment technologies necessary to implement new cleanup standards which require greater reliance on permanent remedies. This is accomplished through technology demonstrations which are designed to provide engineering and cost data on selected technologies.

This project is a field demonstration under the SITE program and designed to analyze the Chemfix Technologies, Inc. solidification/stabilization technology. The technology demonstration took place at a former recycling facility in Clackamas, Oregon. The demonstration effort was directed at obtaining information on the performance and cost of the technology for assessing its use at this as well as other uncontrolled hazardous waste sites. Documentation consists of this report that describes the field activities and laboratory results, provides an interpretation of the data, and discusses the potential applicability of the technology.

Additional copies of this report may be purchased from the National Technical Information Service, Ravensworth Bldg., Springfield, Virginia, 22161, (703) 487-4600. Reference copies will be available at EPA libraries in their Hazardous Waste Collection. You can also call the SITE Clearinghouse hotline at 1-800-424-9346 or (202) 382-3000 in Washington, D.C., to inquire about the availability of other reports.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

The primary goal of the Chemfix Technologies, Inc., demonstration was to evaluate the overall treatment performance and cost of the Chemfix process as applied to a specific hazardous waste matrix at an uncontrolled hazardous waste site. The demonstration took place at the Portable Equipment Salvage Company site in Clackamas County, Oregon. Contamination at the site includes high concentrations of lead, copper, and polychlorinated biphenyls (PCBs) in soil and ash material. Analyses show that metallic lead is the predominant metal species present in the raw waste.

The Chemfix technology is a continuous solidification/stabilization process in which waste material is combined with a proprietary mixture of CHEMSET C-220, a patented silicate reagent, and CHEMSET I-20, a cementitious agent, in a pug mill designed by Chemfix. In general, solidification/stabilization technologies act to reduce the mobility of pollutants. The unique features of the Chemfix technology are the reagents and high capacity and mobility of the process equipment.

The primary criterion used to evaluate the Chemfix technology was its ability to meet the standards set forth in the Land Disposal Restrictions of the Resource Conservation and Recovery Act for lead concentrations in sludges (0.5 mg/L lead in the Toxicity Characteristic Leaching Procedure (TCLP) extract) and a soil treatment demonstration standard of 5.0 mg/L lead in the TCLP extract. Other criteria used included its ability to reduce the concentrations of metals in the leachates and its ability to dechlorinate PCBs over time. The evaluation of the process was based on the results of leaching, chemical, and physical tests.

For all of the treated waste, there were significant reductions in the concentrations of metals in the TCLP extract compared to the concentrations in the extract from the untreated wastes. The physical test data showed the ability of the product to withstand stress due to weathering. There was little to no weight loss as a result of freeze/thaw or wet/dry weathering tests. The permeability of the treated material was generally less than 10^{-6} cm/sec. The unconfined compressive strength varied between 27 and 307 pounds per square inch at 28 days. The excavated material increased in volume between 20 and 50 percent with treatment.

Although some partial dechlorination of PCB was indicated, no conclusions regarding the role of the treatment process in that dechlorination were possible because the by-products of dechlorination were not identified in the treated material. There was no evidence of complete dechlorination of the PCB.

The cost of this treatment process is $40 to $80 per ton of raw waste treated, based on the cost information on the treatment supplied by Chemfix and the materials handling costs experienced during the SITE demonstration. This cost does <u>not</u> include the cost of site preparation, equipment transportation and final placement or disposal of the treated product.

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ABBREVIATIONS

AAS	Atomic Absorption Spectroscopy
ANC	Acid Neutralization Capacity
ANS 16.1	*American Nuclear Society Leach Test*
ASA	American Society of Agronomy
ASTM	American Society for Testing and Materials
BET	Batch Extraction Test
BNA	Base, Neutral, and Acid Extractables
C	Celsius
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
cm	centimeter
CVAAS	Cold Vapor Atomic Absorption Spectroscopy
EC	Electrical Conductivity
EPA	Environmental Protection Agency
Eh	Electromotive Potential
EP	Extraction Procedure
F	Fahrenheit
g	gram
gal	gallon
GC/ECD	Gas Chromatography/Electron Capture Detection
GC/MS	Gas Chromatography/Mass Spectrometry
GFAAS	Graphite Furnace Atomic Absorption Spectroscopy
HDPE	High-Density Polyethylene
hr	hour
ICP	Inductively Coupled Argon Plasma Spectroscopy
kg	kilogram
kwhr	kilowatt/hour
L	liter
lb	pound
M	Molarity
MEP	Multiple Extraction Procedure
mg	milligram
mg/L	milligrams per liter
min	minute
mL	milliliter
mm	millimeter
mv	millivolts
N	Normality
NC	Not Calculated
ND	Not Detected
NPL	National Priorities List
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
PCB	Polychlorinated Biphenyl
PRC	Planning Research Corporation
psi	pounds per square inch
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation and Feasibility Study
RPM	Revolutions Per Minute

ABBREVIATIONS (Continued)

RSD	Relative Standard Deviation
SARA	Superfund Amendments and Reauthorization Act
sec	second
SEM	Scanning Electron Microscope
SITE	Superfund Innovative Technology Evaluation
S/L	Solid to Liquid Ratio
SVOC	Semivolatile Organic Compound
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TMSWC	Test Methods for Solidified Waste Characterization
TSCA	Toxic Substances Control Act
UCS	Unconfined Compressive Strength
μg	micrograms
μg/L	micrograms/liter
μm	micrometer
μmhos	units of conductance
VER	Volume Expansion Ratio
VOC	Volatile Organic Compound
WES	Waterways Experiment Station
XRD	X-Ray Diffraction
yd	yard
ZHE	Zero Headspace Extractor

CONVERSIONS FOR METRIC UNITS

Length				
inches	X	2.54	=	centimeters
inches	X	0.0254	=	meters
feet	X	0.3048	=	meters
Volume				
gallons	X	3.785	=	liters
cubic yards	X	0.7646	=	cubic meters
Weight				
pounds	X	0.4536	=	kilograms
short tons	X	0.9072	=	metric tons
Temperature				
5/9	X	(°Farenheit - 32)	=	°Celsius

Note: 1,000 liters = 1 cubic meter

1,000 kilograms = 1 metric ton

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1.0 EXECUTIVE SUMMARY

1.1 INTRODUCTION

The Chemfix solidification/stabilization technology was demonstrated and evaluated under the Superfund Innovative Technology Evaluation (SITE) program in March 1989. The Chemfix technology is a patented process for solidifying and stabilizing hazardous wastes using proprietary additives, such as CHEMSET C-220, a patented silicate reagent, and CHEMSET I-20, a cementitious agent. The process is designed to be a continuous operation capable of treating large quantities of hazardous wastes rapidly, creating either a friable, soil-like product or monolithic solids.

In the past, Chemfix has used the process for its industrial clients to solidify/stabilize liquids and sludge contaminated with metals. Recently, the firm has begun to test and market the technology for the treatment of soils and wastes with high solid content to broaden the applicability of the technology.

The SITE program conducted a demonstration of the Chemfix technology on soil from the Portable Equipment Salvage Company (PESC) site in Clackamas, Oregon, in March 1989. Chemfix supplied a full-scale unit, reagents, and trained personnel for the demonstration.

As part of the demonstration, the U.S. Environmental Protection Agency (EPA) sampled and analyzed the untreated wastes from the site and the treated product. The primary objective of the tests were to determine the following:

- The ability of the process to solidify/stabilize wastes at the site. The requirements of the Land Disposal Restrictions for electroplating sludges under the Resource Conservation and Recovery Act were used as the evaluation criteria. The leachate standard for lead in electroplating sludges (0.51 mg/L) and a soil treatment standard of 5.0 mg/L were used as benchmarks for evaluating the process.

Other objectives of the project included evaluation of:

- The ability of the process to reduce the concentrations of lead, copper and polychlorinated biphenyls (PCBs) in the extracts from the toxicity characteristic leaching procedure (TCLP)
- The ability of the process to dechlorinate PCBs
- The extent to which the process alters the chemical and physical properties of the wastes and the effect of the alteration on the long-term stability of the material
- The costs and major cost factors associated with the process
- The reliability of the Chemfix equipment

This summary and the following sections have been designed to document the SITE demonstration. Additional discussion of the SITE program and the reports produced under the program is available in Section 2.0 of this document. Section 3.0 describes the Chemfix process. Section 4.0 presents information on the PESC site and the procedures used during the SITE demonstration. Section 5.0 discusses the analytical results from the samples taken during the demonstration. The results of the economic analysis are presented in Section 6.0.

A companion document, Volume II, contains the analytical data, QA/QC data, and other information related to this SITE demonstration.

This Executive Summary briefly discusses the solidification/stabilization technology in general and the unique aspects of the Chemfix process. It also describes the demonstration and summarizes the results.

1.2 SOLIDIFICATION/STABILIZATION TECHNOLOGY AND THE CHEMFIX PROCESS

Chemical solidification/stabilization of hazardous wastes using cement, lime, pozzolans, and other inorganic material have been practiced for many years. Waste-solidifying formulations vary widely and a variety of materials have been added to change the performance characteristics. In general, solidification means making the waste a solid thus limiting the surface area available for leaching. Stabilization implies there is a chemical reaction causing the pollutants to be less mobile. For metals, the terms may be used interchangeably. For organic pollutants, only solidification is appropriate. Because the demonstration focused on lead, the term solidification/stabilization will be used throughout this document.

In general, solidification/stabilization technologies have the following three goals:

- To improve the handling and physical characteristics of the wastes
- To decrease the surface area across which transfer or loss of contained pollutants can occur
- To limit the water solubility of any pollutants contained in the waste

The Chemfix process is intended to solidify/stabilize solids, liquids, and sludge. The unique features claimed by Chemfix include its relatively low cost, high rate of production in a continuous process, controlled processing rate, mobility of the process equipment and patented reagents for reductions in the mobility of pollutants. The limitations of the process defined by Chemfix include the following: water content must be between 25 and 92 percent of the wastes, oil and grease concentrations must be less than 15 percent, and waste feed material must be less than 1 inch in diameter. In addition, some pollutants interfere with the setting of the product. Furthermore, freezing conditions interfere with the ability of the product to cure.

1.3 THE DEMONSTRATION SITE

The PESC site operated as a transformer and metal salvage facility from the 1960s until 1985. It is an area of industrial activity with groundwater near the surface. Operations at the site involved scrapping and recycling power transformers containing PCBs in oils. Salvageable metals from internal wiring and transformer carcasses were processed and recycled. The activities left the soil at the site heavily contaminated with lead, copper, and PCBs, as well as other metals and oil.

Based on the RI/FS (Dames and Moore, 1988) and preliminary sampling by EPA's contractors for the SITE program, EPA selected four areas of waste for the demonstration. The results from analyses of raw waste from these four areas showed very high levels of metal contamination (11,000 to 140,000 mg/kg mean lead concentration) and PCBs (134 to 500 mg/kg mean total PCB concentration) in both soil and ash matrices.

1.4 THE DEMONSTRATION

Site demonstration activities began on March 3, 1989, and lasted until March 24, 1989. The site work included site preparation (providing decontamination facilities, utilities, and other equipment), which required less than 1 week; waste preparation (excavation and sieving to separate particles greater than 1 inch in diameter), which required 1 week; and delivery and setup of the Chemfix equipment, which required 1 week. Many of the setup activities were conducted concurrently. The demonstration of the process required 3 days during which approximately 23 tons of material were processed. This process included an initial test run with clean sand to calibrate and test the operating speed of the equipment. After the tests, demobilization required 1 week.

The demonstration tested both the ability of the Chemfix reagents to immobilize the contaminants in the soil and the ability of the Chemfix equipment and staff to deliver the reagents in the proper proportions and mix them with the waste material.

Chemfix identified a number of factors unique to the demonstration which may have made delivering and mixing the reagents more difficult than would be expected on a normal hazardous waste site remedy. These factors follow:

- Only small quantities of material were made available for treatment during the demonstration to minimize the quantity of material generated. The process equipment was designed to process 40 to 75 tons per hour. The quantities used in the demonstration, 4 to 7 tons from each waste area, made it difficult to achieve a steady production rate because of the limited time for calibration of the equipment.

- The electronic panel normally used to regulate the addition of reagents was broken when the equipment arrived at the site. In the interest of proceeding with the demonstration as rapidly as possible, experienced Chemfix staff calibrated the equipment based on their judgement.

- As a result of the small quantities to be treated and the equipment failure, less reagent was delivered to the treatment process than was planned, which may have affected the physical and chemical properties of the final product.

- The water content of the wastes appears to be different from that expected from the preliminary sampling and therefore, less water was added than required to optimize the chemistry of the treatment.

- Very high concentrations of metals were in wastes and the TCLP extracts from the wastes. Although Chemfix used wastes from a preliminary round of sampling in a bench-scale test that showed adequate treatment with the standard reagents, Chemfix personnel indicate that the addition of another reagent would be expected to improve the results of the process. However, EPA determined the mean concentrations found during the demonstration were within 20 percent of the concentrations found during the preliminary sampling.

1.5 SUMMARY OF DEMONSTRATION RESULTS

The sampling and analysis conducted on the treated and untreated wastes for this demonstration may be grouped into four classes: leaching tests, chemical tests, physical tests, and tests for PCB dechlorination. In addition, air monitoring was conducted during the

demonstration to determine whether PCBs were released to the air as the technology was implemented.

The most important results from this extensive analytical program are presented below.

- Three standards were used to evaluate the effectiveness of the process; the lead concentrations in the TCLP extract from the treated product were compared to the LDR standards for lead in electroplating sludges (0.51 mg/L), an arbitrary demonstration soil treatment standard (5.0 mg/L), and the standard used in the Superfund program interim policy for contaminated soil and debris (99 percent reduction). A comparison of the data showed that 65 percent of the treated material passed the standard of 0.51 mg/L; 70 percent passed the standard of 5.0 mg/L; and 70 percent passed the standard of 99 percent reduction.

- The Chemfix process in this demonstration treated wastes that were extremely variable within each test run. The concentration of lead in the soils ranged from 11,000 mg/kg to 140,000 mg/kg. In the extracts from the TCLP, the concentrations of lead ranged from 0.3 mg/L to 1,300 mg/L. To account for this variability, the mean concentration was used to draw many of the conclusions regarding the nature of the untreated waste and the treated material.

- The results from the TCLP showed substantial reductions in the mean concentrations of lead and copper in the extracts from the treated wastes compared to those in the extracts from the untreated wastes. The reductions varied from 94 percent to 99 percent for lead and 95 percent to 99 percent for copper. These reductions do not account for the volume dilution by Chemfix reagents calculated in Section 5.0.

- The results of the ANS 16.1 test indicate that the leachability index of the treated product passed the Nuclear Regulatory Commission standard for that parameter by several orders of magnitude. However, since lead leached from the treated product in concentrations at a detectable flux, results from this test and other leaching tests should be considered if site specific groundwater conditions indicate a possible problem.

- The multiple extraction procedure (MEP) analyses on the treated wastes generally showed mean concentrations of lead exceeding the EP toxicity standard for a characteristic waste under RCRA in the first extract. Extractions two through ten had much lower mean concentrations of lead although the mean concentration in the last two extractions showed an upward trend. The MEP may be used in RCRA delisting petitions.

- The unconfined compressive strength (UCS) of the treated material does not increase significantly after 14 days, suggesting that the material sets up within 14 days. It met the standard used in EPA's guidance for land disposal (50 pounds per square inch).

- The UCS data also suggest that the product of the treatment process varied in strength. However, it could not be determined if this is the result of poor mixing of the waste and reagent, the lack of homogeneity of the waste, or variations due to the testing procedure. For a single area of the site, the UCS of the product delivered at the beginning of the treatment was very different from the UCS of the product delivered at the end of the treatment process.

- The results from both the wet/dry weathering test and the freeze/thaw weathering test indicated that the tested samples had no significant weight loss compared to the control samples. These results suggest that the products are likely to be durable over time in an exposed environment.

- PCB extraction data show evidence of partial dechlorination of PCBs. The analyses indicate that heavily chlorinated PCB molecules may lose one or more chlorine atoms during treatment. However, the phenomenon may not be due to the solidification/stabilization process only because no by-products of complete dechlorination were found in the treated matrix. Therefore, no conclusions regarding the effectiveness of the process in dechlorinating PCBs can be drawn.

- The air monitoring data show that the PCB concentrations found in the air during treatment were not significantly different from the concentrations found before treatment began. In addition, there was no difference in the concentrations of PCB upwind and downwind of the treatment operations. PCBs do not appear to volatilize from the treatment process under the wet and rainy weather conditions of the demonstration.

- The excavated waste material expanded in volume between 20 and 50 percent as a result of the addition of Chemfix reagents. Those reagents increased the weight of the wastes between 30 and 40 percent.

- The electrical conductivity of the waste increased significantly as a result of the treatment, suggesting an increase in the number of ions in solution. These results indicated the treatment process leaches soluble material. However, the ions leached may be nontoxic.

2.0 INTRODUCTION

2.1 PURPOSE

This section provides background information on the Superfund Innovative Technology Evaluation (SITE) program and the purpose of this report. It also outlines the objectives of the SITE demonstration.

2.2 SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION PROGRAM

Congress enacted the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 to address past hazardous waste disposal practices and the environmental and human health effects of those practices. The original act established a Hazardous Substance Response Trust Fund to deal with costs incurred in cleanups of hazardous materials; this fund has become known as the Superfund. The Environmental Protection Agency (EPA) has proceeded to investigate and remedy potentially dangerous hazardous waste sites and to establish national priorities for site cleanups. The ultimate objective of these efforts is to devise and complete permanent, long-term site cleanups.

In the reauthorization of CERCLA, called the Superfund Amendments and Reauthorization Act of 1986 (SARA), Congress expressed concern over the use of land-based disposal and containment technologies to mitigate releases of hazardous substances at hazardous waste sites. SARA directs EPA to use innovative, alternative, or resource recovery technologies to the maximum extent practicable to permanently solve the problems of hazardous waste sites. Solidification/stabilization technologies, such as the Chemfix process, can be considered innovative treatment technologies for the reduction of mobility of contaminants.

In response to SARA, the Office of Research and Development (ORD) and the Office of Solid Waste and Emergency Response (OSWER) have established a formal program to accelerate the development, demonstration, and use of new or innovative technologies. ORD has also established a program to demonstrate and evaluate new innovative measurement and monitoring technologies. These two program areas exist and are combined in the SITE program.

The primary purpose of the SITE program is to enhance the development and demonstration of innovative technologies applicable to Superfund sites, thereby establishing the commercial availability of these technologies.

The SITE program has four objectives:

1. To identify and, where possible, remove impediments to the development and commercial use of alternative technologies

2. To conduct a demonstration program of the more promising innovative technologies to establish reliable performance and cost information for site characterization and cleanup decision making

3. To develop procedures and policies that encourage selection of available alternative treatment remedies at Superfund sites

4. To structure a development program that nurtures emerging technologies

The demonstration of the Chemfix stabilization technology at the Portable Equipment Salvage Company (PESC) site is one of a number of demonstrations and evaluations of selected technologies conducted as part of the SITE Program. This demonstration program is a significant

ongoing effort involving ORD, OSWER, EPA regions, and the private sector. The objective of the demonstration program is to test and evaluate field-ready technologies. The demonstration program provides Superfund decision makers with the information necessary to evaluate the use of these technologies in future cleanup actions.

2.3 PURPOSE OF THIS REPORT

This report has two objectives: (1) to document the demonstration of the technology under the SITE program and (2) to provide an analysis of the cost and effectiveness of the technology based upon the results of the SITE demonstration. In fulfilling the objectives, this report provides a comprehensive description of the technology and the procedures used in the SITE demonstration, a complete description of the analytical results from the SITE demonstration, and an evaluation of the cost of the Chemfix technology.

2.4 SITE DEMONSTRATION OBJECTIVES AND TEST APPROACHES

The SITE demonstration utilized EPA's approach for establishing data quality objectives (DQO) for the project. With this approach, the project managers identify and prioritize the objectives of the study. These objectives are the focus of the sampling and analysis planned for the project, with most of the resources allocated to the most important goals.

The overall goal of the SITE demonstration was to evaluate the performance, cost, and reliability of the Chemfix technology as applied to contaminated soil from a hazardous waste site. This goal was met through a series of objectives designed by a team consisting of personnel from EPA's Office of Research and Development, Quality Assurance Management Staff, and Office of Solid Waste and Emergency Response; EPA's contractors; and Chemfix. Table 2-1 shows these objectives and the approaches planned to meet them.

EPA selected four areas of the site for the demonstration and all of the areas were sampled and analyzed as part of the project. However, the sampling and analysis program focused on one of these areas. The costs of the extensive analysis necessary to meet the objectives of the project were too high to conduct such analyses on all four areas. EPA selected one area for extensive analysis based on the preliminary sampling results, which indicated that it contained moderate to high concentrations of PCB and lead in a soil matrix.

Table 2-1

Test Methods and Approaches for Meeting the Demonstration Objectives

Objectives	Approach/Method
Primary	
• Determine whether wastes treated by the technology meet or exceed RCRA land ban and arbitrary soil standards.	Compare lead concentrations in TCLP leachates of treated wastes to standards for RCRA listed waste (electroplating sludges) and arbitrary soil standards.
Secondary	
• Determine the effectiveness of the process in reducing lead and copper concentrations in leachates obtained using the TCLP on raw and treated wastes.	Compare lead and copper concentrations in TCLP leachates from treated wastes with those from raw wastes.
• Determine the effectiveness of the process in reducing PCB concentrations in TCLP leachates to 1 ppm or less.[1]	Compare PCB concentrations in TCLP leachates from treated wastes with those from raw wastes.
• Determine whether the treatment process dechlorinates PCBs over time.	Compare PCB concentrations in treated wastes at 15, 30, 45, and 60 days after treatment using EPA Method 680. Identify the presence of reaction products, using a new analytical approach, to determine whether dechlorination, rather than adsorption, has occurred during the curing process.
• Determine baseline physical properties of the raw wastes to establish a basis for evaluating process performance.	Analyze raw wastes for particle size, percent moisture, standard proctor value, porosity, bulk density, and specific gravity.
• Determine the chemical properties of the raw wastes to establish a basis for evaluating process performance.	Analyze raw wastes for acid neutralization capacity, TOC, pH, Eh, oil and grease, electrical conductivity, total PCBs, total lead, total copper, lead compounds, humic acid, and dioxin.
• Determine physical properties of treated wastes to indicate their long-term permanence and placability.	Subject treated wastes to permeability, wet/dry, freeze/thaw, unconfined compressive strength, water content, bulk density, specific gravity, and porosity tests.

Table 2-1

Test Methods and Approaches for Meeting the Demonstration Objectives (Continued)

Objectives	Approach/Method
• Determine chemical properties of treated wastes.	Analyze treated wastes for lead, copper, PCBs, TOC, pH, Eh, oil and grease, electrical conductivity, and acid neutralization potential.
• Determine leaching properties of treated wastes to indicate their long-term chemical stability.	Subject treated wastes to a number of different leaching tests.
• Determine the structural characteristics of the treated wastes.	Conduct x-ray diffraction, petrographic, and scanning electron microscopy examinations of the treated and raw wastes.
• Determine whether significant PCB concentrations are released to the air by the treatment process.	Monitor the PCB air concentrations in the immediate vicinity of the Chemfix processing equipment during the treatment process.
• Determine the dilution effects on any reductions of lead and copper concentrations in leachates obtained from treated wastes.	Measure the mass of wastes, water, and treatment reagents used in each test run and use these measurements to calculate dilution factors.
• Determine the effects of aging on the leachability, acid neutralization capacity, and strength of the treated wastes.	Conduct long-term analyses of TCLP and ANS 16.1 leachable metals (copper, lead, and pH) and test for unconfined compressive strength and acid neutralization capacity.
• Determine total cost and major cost factors associated with the process.	Evaluate the costs of all materials, equipment, and services needed to complete the demonstration.

[1] This objective could not be addressed because PCB concentrations in the TCLP leachates of raw and treated wastes (preliminary sampling) did not exceed detection levels.

Note: RCRA, Resource Conservation and Recovery Act; TCLP, toxicity characteristic leaching procedure; PCB, polychlorinated biphenyl; TOC, total organic carbon; ANS, American Nuclear Society

3.0 CHEMFIX PROCESS

3.1 PROCESS DESCRIPTION

The Chemfix process is a chemical fixation and solidification/stabilization process that can treat solids, liquids, and sludges, provided the wastes are between 8 and 75 percent solids by weight. This technology uses the following materials, measured by weight or volume and added to the continuous process:

- Waste material (measured by weight)
- CHEMSET I-20 dry reagent (measured by weight)
- CHEMSET C-220 liquid reagent (measured by volume)
- Water (measured by volume)

The Chemfix process for treating solids includes the following operations:

- A conveyor belt (primary conveyor) moves waste from the feed hopper where it is stockpiled, to the weight feeder, where it is measured.

- The homogenizer mixes the measured waste and water. The quantity of water added to the homogenizer depends on the quantity of waste measured and is controlled automatically.

- The process mixer uses a Chemfix-designed pug mill to blend the wetted waste, liquid reagent, and dry reagent. The dry reagent is fed into the process mixer through a dry reagent feeder and the liquid reagent is pumped into the process mixer using a variable-speed feed pump. When mixing is complete, the product is discharged. During the demonstration, a positive displacement pump was substituted for the variable-speed feed pump.

Chemfix advertises the following features for its treatment process (Salas, 1980):

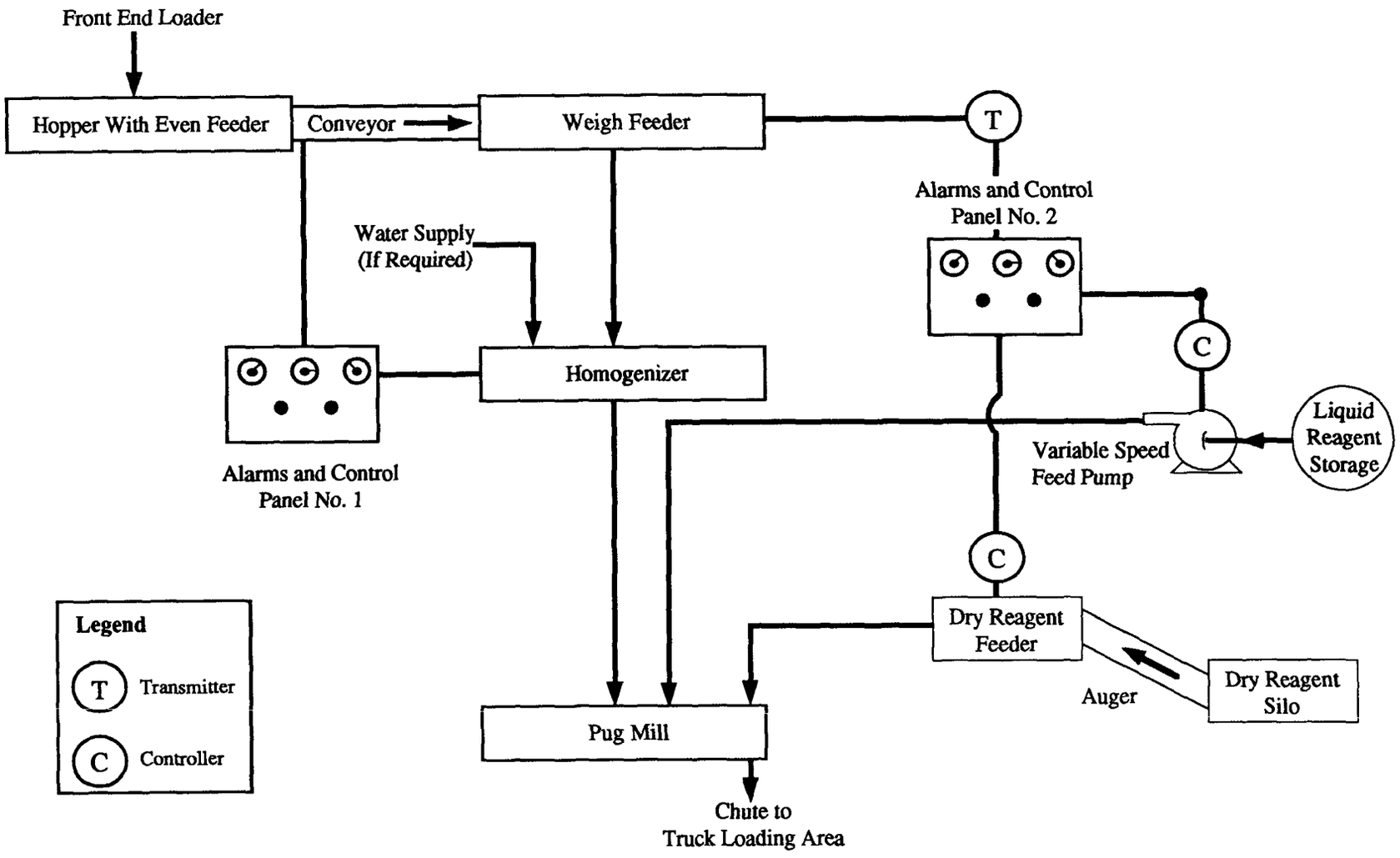
- Relatively low cost
- Readily available reagents
- Controlled solidification rate
- High continuous throughput rate
- Mobility of process equipment

Figure 3-1 illustrates the Chemfix process.

3.2 INNOVATIVE FEATURES OF THE CHEMFIX PROCESS

The Chemfix treatment system is a mobile, self-contained, continuous processing unit mounted on a flatbed trailer. It solidifies and stabilizes wastes based on chemical reactions of complex silicates. It is intended to treat heavy metals and organic compounds with high molecular weights. The innovative features of the system include the proprietary reagents, the pug mill designed by Chemfix, and the continuous nature of the process. Because it is a continuous process, waste material can be treated more quickly, lowering the cost per ton of material treated.

Figure 3-1 Chemfix Technologies, Inc.
High Solids Handling System Block Process Flow Diagram



3.3 PROCESS CHEMISTRY

The Chemfix process is based on the use of a proprietary family of polysilicates (CHEMSET C-220) and dry calcium-containing reagents (CHEMSET I-20). The chemistry is assisted as needed by reaction-promoter additives. The combination and proportions of reagents are optimized for the waste stream (solid, liquid, or sludge) requiring treatment. Chemfix designed the process to reduce the mobility and toxicity of metals as well as base, neutral, and acid (BNA) organics with high molecular weights. The two-part inorganic chemical system reacts with polyvalent metal ions, certain other waste components, and itself to produce a chemically and physically stable solid matrix (Chemfix, 1987).

Chemfix indicates that the matrix that is produced is based on tetrahedrally coordinated silicon atoms alternating with oxygen atoms along the backbone of a linear chain. The charged-side group (in this case, oxygen) reacts with polyvalent metal ions, resulting in strong ionic bonding between adjacent chains. This bonding forms a cross-linked, three-dimensional polymer matrix that has a high stability, a high melting point, and a rigid friable structure (Salas, 1980).

Chemfix explains that three classes of interactions take place. First are the very rapid reactions between CHEMSET polysilicates, certain reaction promoters, and metal ions, producing insoluble metal silicates that cannot be resolubilized and are resistant to breakdown under severe environmental conditions. The second set of reactions occurs between the polysilicate molecules and the reactive components, including calcium oxide within the dry reagent, to produce a gel structure. The gel holds ions in place in chemical and physical bonding mechanisms, thereby acting as an ion-exchange resin. Other waste components such as oils are also trapped in the structure and thereby immobilized. The third class of reactions occurs between the dry reagent and the waste and water (both free and contained) as the dry reagent undergoes a series of hydrolysis, hydration, and neutralization reactions (Chemfix, 1987).

3.4 EQUIPMENT SPECIFICATIONS

The Chemfix soil treatment system is a self-contained process unit mounted on a flatbed trailer. The system consists of several pieces of equipment that are connected both physically and electronically. This equipment is described below. In some cases the arrangement of the equipment may vary with site conditions. The system used at the PESC site is designed to handle 40 to 75 cubic yards of material per hour. The demonstration project did not approach this treatment rate, however, because of the small quantity of wastes to be treated. In each test run, approximately 4 to 7 cubic yards of material were treated. Each of these test runs lasted from 10 to 20 minutes. The function of each important piece of equipment in the processing unit demonstrated at the PESC site and its description are provided below.

3.4.1 Feed Hopper

The feed hopper is where waste material to be treated is introduced, by front-end loader or other earth-moving equipment into the treatment system. The Chemfix feed hopper used at the PESC site has approximate dimensions of 9 feet x 16 feet and a capacity of 15 to 20 cubic yards. Only 30 percent of its capacity was used for each of the test runs at the PESC demonstration.

3.4.2 Primary Conveyor

The 40-foot long conveyor belt transfers waste feed material from the feed hopper to the weigh feeder. Its speed can be automatically adjusted.

3.4.2 Weigh Feeder

The weigh feeder receives waste material from the conveyor belt and continually weighs it as it enters the homogenizer. The feeder can feed up to 150,000 lb/hour with an accuracy of ± 1,500 lb/hour. The weigh feeder is electronically connected to the water flow control system and the two reagent feed systems. Waste is moved through the weigh feeder to the homogenizer. The weight of soil will regulate the water flow rate to the homogenizer through a flow-indicating water control station.

3.4.4 Water Flow Control System

The water flow control system receives an electronic signal from the weigh feeder signaling the amount of waste entering the homogenizer. This system then adds water to the waste at a predetermined rate as the waste passes into the homogenizer. The amount of water to be added depends on the amount of waste in the homogenizer. The system can deliver up to 9,000 gallons/hour with an accuracy of ± 450 gallons/hour. This system was not necessary at the PESC site, because the liquid reagent was diluted before treatment.

3.4.5 High Speed Shear Process Mixer (Homogenizer)

The homogenizer mixes waste material from the weigh feeder and water from the water flow control system.

3.4.6 Dry Reagent Feeder

The dry reagent to be used in the Chemfix process is transported to the treatment site and placed in a dry reagent storage silo. From this silo it is transferred by an auger to the reagent feeder and from the reagent feeder it is transferred to the mixer by gravity. The speed of the auger is controlled in conjunction with the liquid reagent storage tank from a control panel so that both are added to the process mixer in proportion to the waste feed material. It is designed to handle up to 54,000 lb/hour with an accuracy of ± 100 lb/hour.

3.4.7 Dry Reagent Storage Silo

The design capacity of the silo is approximately 120,000 lb. Only 25,000 lb of dry reagent were stowed during the demonstration at the PESC site. It is equipped with high- and low-level sensors and alarms. The silo is also equipped with a baghouse dust collector. The baghouse dust collector is operated only during the transfer of dry reagent from the bulk reagent transport vehicle to the dry reagent storage silo.

3.4.8 Liquid Reagent Storage Tank

The 10-foot-diameter liquid reagent storage tank (100,000 lb capacity) is used to hold the liquid reagent that is transferred to the process mixer or homogenizer as required, by the liquid reagent transfer pump.

3.4.9 Liquid Reagent Transfer Pump

The liquid reagent transfer pump regulates the amount of liquid reagent transferred from the liquid reagent storage tank to the process mixer or homogenizer. The pumping rate is manually set on the control panel and varies according to the weight signal received from the weigh feeder.

3.4.10 High-Speed Shear Mixer (Process Mixer)

In the process mixer, a Chemfix-designed pug mill is used for blending wetted waste material from the homogenizer, dry reagent from the reagent silo, and liquid reagent from the liquid reagent storage tank. The waste material is transferred to the process mixer by gravity. The liquid reagent is pumped into the process mixer. The dry reagent is transferred to the process mixer by gravity or an auger. After these ingredients are mixed, they are discharged. For this demonstration, the product was discharged to 1/2-cubic yard plywood boxes.

3.4.11 Modifications for Sludges and Liquids

When sludges or liquid wastes are treated, the Chemfix equipment must be modified. A typical mobile sludge treatment process consists of a sludge tank, magnetic flow meter, sludge supply pump, and two product-transfer pumps instead of the feed hopper, conveyor belt, weight feeder, and homogenizer.

3.5 CHEMFIX PROCESS LIMITATIONS

Although the Chemfix process has been used to treat various types of wastes such as automotive wastes, fly ashes, metal-finishing wastes, mine tailings, municipal and industrial sludges, and petrochemical wastes, it has specific limitations for which it may not be used.

The Chemfix process requires sufficient space to accommodate all its treatment equipment. For example, it requires a 25 foot x 40 foot concrete pad with curb for the process unit and a 50 foot x 150 foot graded process area covered with gravel for loading and parking. Additional space is required to accommodate all the treated material, used protective equipment, and other wastes generated until they are disposed of into a landfill.

According to Chemfix, the Chemfix process is not amenable to wastes with the following characteristics:

- Water content greater than 95 percent or less than 25 percent
- Oil and grease concentrations greater than 15 percent in the soil
- Waste feed material bigger than 1 inch
- Soil pH less than 2 or greater than 12

4.0 THE SITE DEMONSTRATION

4.1 PURPOSE

This section describes the site and wastes used for the demonstration of the Chemfix process. It also presents the procedures used to characterize the waste and treated products and documents the activities conducted during the demonstration.

4.2 DESCRIPTION OF THE SITE

The Environmental Protection Agency (EPA) selected the Portable Equipment Salvage Company (PESC) site for the demonstration of the Chemfix technology in cooperation with the developer of the technology. This decision was based on the types and concentrations of pollutants present. Located in an industrial area, the 2-acre site is rectangularly shaped, and the most heavily contaminated part of the site is enclosed with a fence. The neighboring property, the D&M Auto Wrecking Yard, has been found to be contaminated, also. Material from both properties was used in the demonstration test. Figure 4-1 is a diagram of the site.

The PESC site served as a transformer and metals salvage facility from the early 1960s until about 1985. Operations at the site involved scrapping and recycling power transformers containing PCBs in oils. Salvageable metals from internal wiring and transformer carcasses were processed and recycled. Transformers and other recycled electrical equipment were treated in a furnace to eliminate insulation and other noneconomic elements. Waste transformer oil was used to fire furnaces and metal smelters at the site.

Fill covers most of the PESC site and the D&M Auto Wrecking Yard. This fill consists of coarse gravel, sand, and silt and has been placed on the site and spread to a thickness of 6 to 24 inches. The soil beneath the fill is a medium to dark brown silty soil that contains a few fine roots and some clay. Ground water is found 5 to 13 feet below the surface. The area receives 45 inches of rainfall per year.

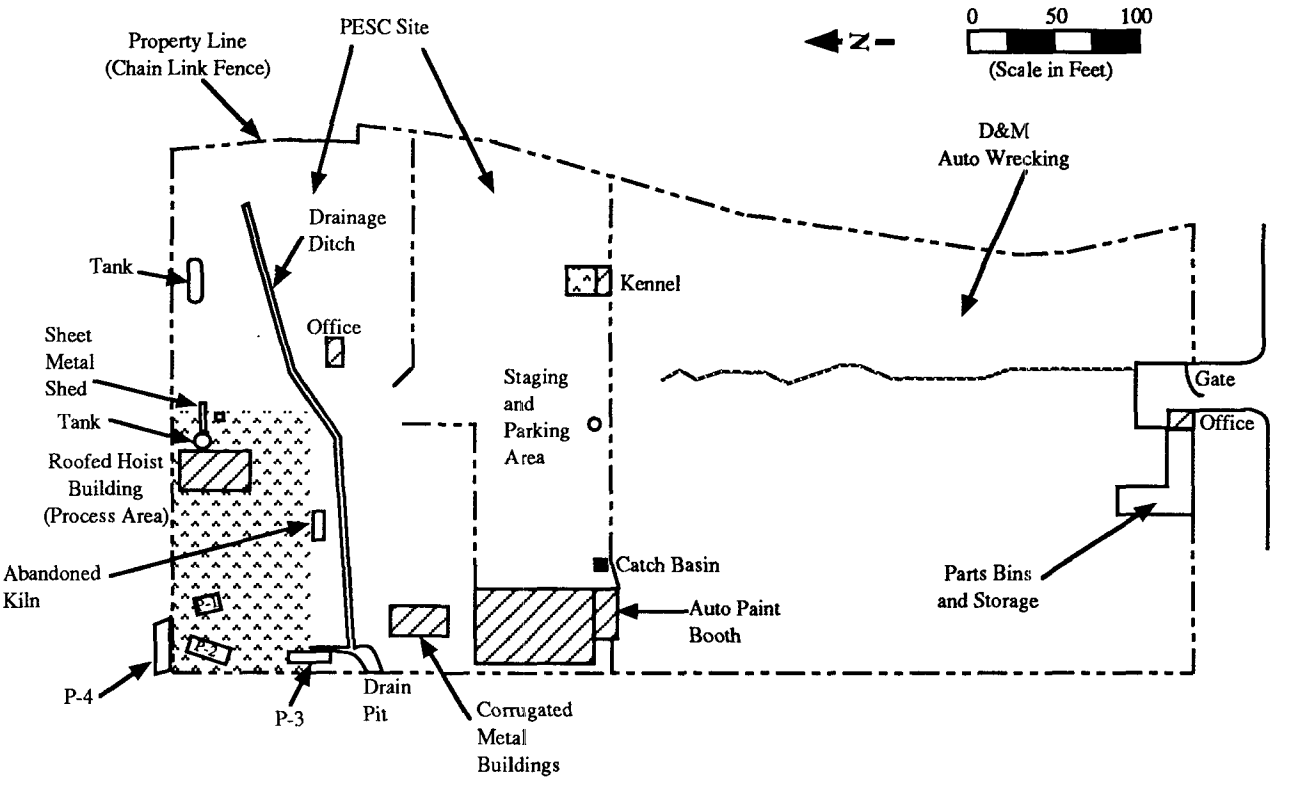
In 1986, after operations at the site had ceased, EPA conducted preliminary sampling and confirmed the presence of polychlorinated biphenyls (PCBs), metals, and polycyclic aromatic hydrocarbons (PAHs) in surface soils and waters on-site and near-site. EPA determined that Pacific Power and Light (PP&L) had sold surplus transformers to PESC in 1981 and 1982. A consent order (EPA Docket No. 2086-07-06-2615/106) dated May 7, 1987, required PP&L to conduct a site stabilization and a focused remedial investigation/feasibility study (RI/FS) of the site.

The site stabilization was conducted in 1987. The RI was conducted in late 1987 and early 1988 by Dames and Moore for PP&L. This investigation consisted of sampling and analyzing surface soils, surface water, subsurface soils, and ground water. (Dames and Moore, 1988).

4.3 DESCRIPTION OF THE PESC WASTES TREATED IN THE DEMONSTRATION

Surface soil, subsurface soil, and ground water were sampled and analyzed under the focused RI to chemically characterize the PESC site. In addition, an EPA sampling team visited the site on July 26, 1988, to confirm the findings of the RI, collect samples for a bench-scale treatability test with the Chemfix process, and conduct a sieve analysis to determine the percentage of the soils that would pass a 1-inch sieve.

Figure 4-1 The Portable Equipment Salvage Company Site



Legend

- Building Location
- Concrete Surface
- P-3 Pond Location and Number
- Approximate Location of ±300 Gallon Gasoline Storage Tank (Empty)
- Fence
- Surface Drainage

Reference : Figure 7-1. *Dames and Moore RI Report, 1988*

The major contaminants at the site are PCBs from transformer oils and metals from the smelting operations. Metals of concern include lead, copper, zinc, and mercury. The most heavily contaminated areas within the site include the transformer-dismantling area on the south side of the roofed hoist building, the roadway in and out of the site where vehicles may have tracked contaminants, areas of surface runoff and ponding, and an ash disposal area located on the D&M Auto Wrecking Yard. Soil contaminated with lead, copper, and PCBs is fairly widespread on both the PESC site and the D&M property, but the contamination rapidly attenuates with depth. Generally, only the top 2 to 4 feet of soil are contaminated, with the more heavily contaminated soil occurring in the top 1 foot. Other contaminants in soils are present in relatively minor concentrations at the same locations.

Based on analytical results from EPA's initial sampling effort and the focused RI, on-site soil contamination can be summarized as follows:

Contaminant	Concentration(mg/kg)
PCB	0.1 to 4,900
Lead	11 to 139,000
Copper	14 to 126,000
Zinc	86 to 11,000
Mercury	≤22
Other priority pollutant metals	≤427
Chlorinated benzene[a]	55 (191 in the duplicate sample)
VOCs	trace level
Oil and grease	44 to 78,000
PAHs	Not detected
Dioxin and furans (ash)	<1.00 ug/kg

[a] This sample was taken below the concrete pad of the PESC site. Samples taken from other areas exhibited trace levels.

Based on the results of the initial sampling effort, EPA decided to treat soil from four site areas (Areas A, C, E, and F, Figure 4-2) in the demonstration of the Chemfix technology because these areas exhibit medium to high concentrations of lead, copper, and PCBs and represent different matrices (soil and ash).

4.4 ACTIVITIES DURING THE DEMONSTRATION

Table 4-1 presents the chronology of the major field demonstration events.

4.4.1 Site Preparation

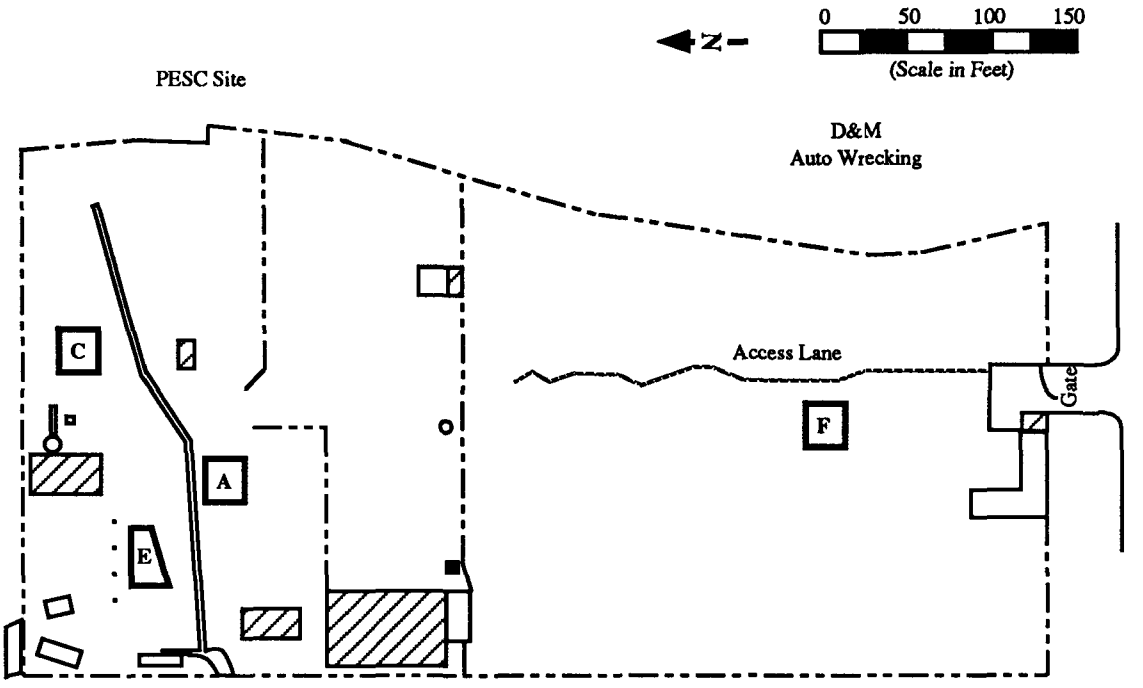
Before the demonstration, the following tasks were performed to get the site ready for a treatment operation:

- Mobilizing equipment: Waste preparation and handling equipment such as back hoes and loaders, screens, and fork lifts were brought to the site and an office trailer was set up. Table 4-2 lists this equipment.

- Providing utilities: Electrical and telephone service for the trailer, water and electricity for the process equipment, and sanitary services for the staff were provided.

- Constructing facilities: A decontamination pad for vehicle decontamination, a facility for personnel decontamination, and a storage

Figure 4-2 Waste Feed Areas at the PESC Site



Legend

— - - — Fence

- - - - - - - - - Surface Drainage

F Waste Feed Locations

Note: A, C, E, and F — Waste Feed Locations

Reference : Base map drawn from Figure 7-1 of *Dames and Moore RI Report*

Table 4-1

Chemfix Demonstration Chronology

Waste Preparation	Date
Office trailer setup	March 3
Establishment of health and safety zones	March 3
Establishment of excavation areas	March 4
Excavation of waste material	
Areas A, C, E	March 6
Area F	March 11
Completion of decontamination pad	March 7
Screening of waste material	
Area A	March 7
Areas C and E	March 8
Area F	March 11
Raw waste sample collection	
Areas A, C, and E	March 8
Area F	March 12

Operations	Date
Arrival of Chemfix equipment	March 9
Beginning of Chemfix equipment setup	March 10
Completion of Chemfix equipment setup	March 15
Chemfix equipment calibration, reagent mix run, and sampling	March 15
Test runs and treated waste sampling	
Areas A, E, and F	March 16
Area C	March 17
Decontamination, demobilization, and site restoration activities	March 18 through 24

Table 4-2

Major Equipment Used for Chemfix Demonstration

Number	Item
1	Office trailer (12 feet wide x 42 feet long)
1	416 Caterpillar loader/backhoe
1	910 Caterpillar loader
1	RD 40 Read Screen-All
1	Grove RF 522 crane (21-ton capacity)
1	JCB 930 fork lift
1	High-reach fork lift
1	Vibratory compactor
1	Caterpillar engine generator (481 amp) for Chemfix equipment
1	20,000-gallon Baker tank
1	MQ 40 generator for trailer
1	Weight-Tronix scale
7	Steel plates
1	Air compressor, air pump
1	2,000-psi Landa pressure washer
1	3,000-psi Landa pressure washer
1	Nonpowered roller conveyer
154	Plywood boxes

Chemfix equipment, including pug mill, homogenizer, conveyer, feed hopper with even feeder, weight feeder, silo with baghouse, liquid reagent transfer pump, liquid reagent storage tank (Matlack tank rented)

facility for decontamination water (Baker tank) were set up. In addition, storage areas for process and treated products were prepared and 0.5-cubic yard plywood boxes for the treated waste were constructed. Finally, steel plates were placed over an existing ditch to permit vehicular traffic.

- Providing a security guard: A security guard was provided (8 hours per day) during the demonstration period.

4.4.2 Waste Preparation

Approximately 7 to 8 cubic yards of contaminated soil were excavated from each of Areas A, C, and E, using a backhoe and loader. The excavation depth was approximately 1 foot. The excavated soil was mixed using the backhoe, piled near the excavated area and covered with a 6-mil plastic sheet (polyethylene film).

The material that was screened through a 1-inch mesh was placed on a concrete pad, in a pile between two layers of plastic sheet. The rejected material from the screen was returned to the excavated area. The rejected material was approximately 30 to 40 percent of the original material.

Area F (ash pit) was excavated to approximately 2 feet. The excavated material (ash and soil mixture) was transported to the screening unit, screened and piled as described above.

Throughout the field demonstration, including waste and site preparation, all fieldwork in the contaminated zone was performed in Level C protective equipment.

4.4.3 Chemfix Equipment Mobilization and Setup

Chemfix mobilized its equipment at Chemfix headquarters in Metairie, Louisiana, and transported it on three trailer beds to the PESC site. Major equipment delivered to the site included a hopper with even feeder, weigh feeder, homogenizer, pug mill, dry reagent feeder, dry reagent storage silo, dust baghouse, liquid reagent transfer pump, control panel, operator's platform, and instrumentation. A 40-foot conveyer belt was purchased locally and brought to the site. Chemfix arranged for a local chemical supplier to deliver a liquid reagent storage tank (Matlack tanker) containing the diluted liquid solution (CHEMSET C-220D). Table 4-2 lists the major equipment used in site and waste preparation and in the test runs. A truck brought approximately 25,000 lb of CHEMSET I-20, the dry reagent, which was transferred pneumatically to the Chemfix silo. It took approximately 1 week to set up the equipment.

4.4.4 Test Runs

At this site, Chemfix demonstrated its technology in five test runs, one run to calibrate the equipment and one run to treat waste material from each of four areas of the site (Areas A, C, E, and F).

4.4.4.1 Calibration Run

Chemfix calibrated its equipment using approximately 10 cubic yards of clean sand. Chemfix poured the weighted sand (948 lb) into the feed hopper and it was carried through the belt conveyer to the weigh feeder. The reading on the weigh feeder totalizer was 0.49 ton (980 lb).

Therefore, the weigh feeder weighed 32 pounds or 3.4 percent more than the true weight. This difference is accounted for in each of the readings listed in Table 4-3.

In addition to calibrating the weigh feeder, Chemfix used the clean sand to test the speed of the equipment and the proportions of wet and dry reagent needed to produce a quality product, based on the operator's observation. The demonstration equipment has a maximum

treatment capacity of 75 tons per hour (TPH). Since the material to be treated was less than 10 cubic yards, the equipment was adjusted to run at about 20 to 30 TPH. The total operating time was 37 minutes for the calibration run.

The following amounts of clean sand and reagents were used to calibrate the equipment.

Sand	9.07 tons
CHEMSET I-20	2.3 tons
CHEMSET C-220	273 gallons

Technicians added water to the waste indirectly, by diluting the liquid reagent with water (15 percent water, by weight) (reported by Chemfix). The chemical supplier delivered the diluted liquid reagent to the site. This test run generated a total of 23 plywood boxes of treated product and materials used to clean the equipment. The boxes for all the test runs were lined with plastic sheeting.

During the operation, EPA's contractors worked with Chemfix operating personnel to check the process data. The operating data for raw waste and cement were read from the weight feeder totalizer and reagent totalizer, respectively. The data for the liquid reagent were recorded from the flow meter. The operating time was checked with a stopwatch. Table 4-3 shows the operating data from the test runs.

4.4.4.2 Area E Run

After the equipment calibration run was completed, the first actual test run was performed on the screened waste material from Area E. The waste material was loaded into the Chemfix hopper, using the front-end loader with a 1-cubic yard bucket.

The even feeder of the feed hopper fed the soil onto the belt conveyer, where the conveyer lifted the soil onto the weight feeder. The amount of soil to be processed was measured at the weight feeder. From the weight feeder, the soil was fed into the homogenizer by gravity.

The diluted liquid reagent was pumped into the homogenizer and mixed with the soil. The homogenized soil was then transferred by gravity into the pug mill, where the soil was mixed with the dry reagent that had been fed from the storage silo. After treatment, the treated slurry was discharged into the reinforced 0.5-cubic yard plywood boxes on a nonpowered roller conveyer placed under the pug mill unit. This process continued until the pug mill was emptied.

During the processing of this material, copper wires that passed through the vibrating screen clogged the discharge end of homogenizer and the operation had to be stopped. After these wires were removed, the operation was started again. Because of this problem, three boxes of incompletely treated waste were generated (one box of mostly dry reagent and two boxes of mostly liquid reagent).

Fifteen plywood boxes were filled with treated waste. From these, Chemfix selected six boxes as representative samples of treated waste by observing the product's quality. Most of the rejected boxes were generated during the initial equipment startup period and included incompletely treated waste. The sampling crew sequentially numbered the selected boxes with spray paint and collected treated waste samples from these boxes. Operating data obtained from the first test run are presented in Table 4-3.

After treating the material, Chemfix decontaminated its equipment, including the even feeder, homogenizer, and pug mill. The cleanup waste was collected in plywood boxes. It took approximately 40 minutes to complete the decontamination activity.

4.4.4.3 Area A Run

The second test run was performed on the screened waste material from Area 4. The operating data from the second test run are presented in Table 4-3. Thirteen boxes were

Table 4-3

Operating Data Obtained During the Demonstration Test Runs

Area	Raw Waste[a] (Ton)	Dry Reagent (Ton)	Percent Dry Reagent[b]	Liquid Reagent (Gal)	Liquid Reagent[c] (Gal/Ton)	Operating Time (Min)	Downtime (Min)
E	6.37	1.18	18.5	203	31.9	19	10
A	4.65	0.58	12.5	177	38.1	20	0
F	5.99	1.26	21.0	205	34.2	16	12
C	5.68	0.86	15.1	216	38.0	13	1

a Corrected values are based on the weight feeder calibration

b Chemfix-predicted value from preliminary study was 16 percent by weight

c Chemfix-predicted value from preliminary study was 41.6 gal/ton of raw waste

generated, from which Chemfix selected six boxes as representative samples. The staff from Chemfix rejected the boxes that included incompletely treated waste to ensure the analyses were run on good-quality product.

4.4.4.4 Area F Run

The third test run was performed on the screened ash and soil mixture from Area F (ash pit). During this test run, the operation was stopped twice. In the first case, a large rock, inadvertently mixed with the screened material, broke one flight blade of the flight screw shaft of the even feeder. After the broken flight blade was removed, the operation was resumed. The operation was stopped again when one of the boxes became stuck on the roller conveyer and began to overfill with the treated product. The operating data obtained from the third test run are presented in Table 4-3. Nineteen boxes were generated, from which Chemfix selected six boxes as representative samples.

4.4.4.5 Area C Run

The fourth test run was performed on the screened waste material from Area C. During this test run, one plywood box became stuck on the roller conveyer and overfilled with the treated material. The operation had to stop for approximately 1 minute. The operating data from the fourth test run are presented in Table 4-3. Eleven plywood boxes of treated material were generated, from which Chemfix selected 10 boxes as representative samples. After completing the fourth test run, Chemfix decontaminated its equipment. The cleanup waste was contained in the plywood boxes.

4.4.4.6 Deviations

There were two deviations from the demonstration plan. First, the amount of waste material processed was approximately 47 percent of the amount planned (10 cubic yards for each test run) because the rejected material from the screening process was high and excavation was slightly less than planned. Second, Chemfix added water indirectly into the homogenizer by diluting the liquid reagent solution. Neither change affected the performance of the equipment although Chemfix appears to have miscalculated the water needed.

4.5 SITE RESTORATION

After the test runs were completed, the following site restoration activities were conducted. The excavated areas (Areas A, C, E, and F) at the site were back-filled, initially with the rejected gravel from the screening operation, and then with imported crushed stone and gravel. The areas were compacted with a wheel loader and leveled.

The vehicle decontamination pad was disassembled and back-filled with soil and sand. In addition, general site cleanup was conducted. All wastes generated were placed in drums, plywood boxes, and a dumpster, and these containers were properly stored at the site for disposal. All Chemfix equipment and waste preparation equipment were decontaminated and demobilized. The office trailer was cleaned and demobilized. Finally, the gate and security fence in the contaminated area were restored to their original condition.

4.6 WASTE DISPOSAL

Several types of wastes required disposal after the demonstration. Unused waste feed material, disposable health and safety gear, wastes generated during decontamination and equipment startup, and products of the Chemfix process all required disposal.

The plywood boxes containing treated waste and cleanup waste were temporarily stored on an existing concrete pad in front of the roofed hoist building. The concrete pad was lined

with a 20-mil plastic sheet and the boxes were stacked four high and three wide. The liner was folded to the sides of the boxes and stapled to the sides of the boxes. A 6-mil plastic sheet was then placed over the top of the stack and stapled to the sides. Plywood boxes containing unused cement and treated sand were also covered with a 6-mil plastic sheet.

EPA disposed of the treated waste and hazardous waste drums at a Resource Conservation and Recovery Act (RCRA) - and Toxic Substances Control Act (TSCA)-approved landfill site. The nonhazardous treated sand was sent to a sanitary landfill for disposal.

According to the analytical data, the decontamination water in the Baker tank contained no PCBs. The metal concentration was less than 1 ppm. The settled soil (or sludge) in the tank contained 170 ppm PCBs and 1,800 ppm lead, thus it is classified as a RCRA hazardous waste with PCBs in excess of 50 ppm and is subject to the Land Disposal Restrictions. After the water and sludge were separated, the sludge was shipped to the RCRA- and TSCA-approved incinerator for high-temperature incineration. The water was discharged after a discharge permit was obtained.

4.7 SAMPLING PROCEDURES

Samples were collected before and after each test run by the sampling and analysis contractor. Samples were collected and analyzed in accordance with the established sampling and analysis plan (PRC SITE Team, 1989). The sampling plan was designed to provide statistical comparisons of the physical and chemical characteristics of the contaminated soils before and after treatment. These statistical comparisons provide the basis for determining the effectiveness of the Chemfix process.

This section describes sampling procedures for raw waste, reagent mix, treated waste, and air-monitoring samples, and describes field quality control procedures.

4.7.1 Raw Waste Sampling

Raw waste samples were taken to establish the chemical and physical characteristics of the waste material. Raw waste samples were collected in accordance with the established sampling requirements, (PRC SITE Team, 1989). Prior to test runs, samplers collected raw waste samples from each of the four screened waste piles (Areas A, C, E, and F), using an auger. Five depth-integrated samples were collected randomly from each waste pile, placed on a plastic sheet, and mixed with a stainless-steel scoop. The mixed sample, representing one replicate sample, was scooped into several individually labeled sample glass jars for shipment to the laboratory for analyses. In this way, required replicate samples were collected from each waste pile. Additional samples were collected from each waste pile and held in reserve.

There were three deviations from the established sampling requirements. Because of rocks and gravel in the ground at the four designated excavation areas, the Radian sampling crew was unable to obtain bulk density samples using shelby tubes in any of the areas, or to conduct in-situ hydraulic conductivity tests in Area C. As directed by the EPA project manager, bulk density was determined on one sample of screened material from each of the four areas at the site. The in-situ hydraulic conductivity tests were not conducted. The demonstration plan also called for screening raw and treated waste material at the site for extract tests such as TCLP, using the 3/8-inch screen. The sieved treated waste was to be poured into cardboard molds for curing. Because of the difficulty of screening the treated material, neither raw nor treated material was screened with the 3/8-inch screen. This change in plan is not expected to affect the results of the tests.

4.7.2 Reagent Mix Sampling

As described in Section 4.4.4.1, Chemfix performed an equipment calibration run using approximately 10 cubic yards of clean sand, as well as liquid reagent and dry reagent. Originally,

all reagents were to be mixed in a 5-gallon mixing vat and samples were to be collected from the mixing vat. However, the EPA field quality assurance contractor suggested that samples be taken from treated sand so that any contaminants from Chemfix equipment would be accounted for. The treated sand was sampled to determine whether additional contaminants were being added to the reagent mix. Samples of the treated sand slurry were collected immediately after it had been discharged from the pug mill. Slurry samples were transferred from the plywood boxes into wax-coated cardboard molds for curing. Samples were collected in accordance with the established reagent mix sampling requirements (PRC SITE Team, 1989).

4.7.3 Treated Waste Sampling

Samples of treated waste were needed to determine the extent of waste stabilization. Treated waste samples were collected from the slurry after it had been discharged from the pug mill and were transferred into wax-coated cardboard or molds. The molds were individually labeled, placed in open storage containers, covered with plastic sheeting, and allowed to cure for 2 days at the site. After the curing period, the molded samples were transported to the laboratory for testing and analysis. Treated waste samples were collected in accordance with the sampling requirements (PRC SITE Team, 1989).

Samplers collected samples required for the on-site test by scooping slurry from the plywood boxes after the treated material was discharged from the pug mill. For each test run, the slump test (ASTM C143) was performed on the slurry in the first, middle, and last plywood forms of those designated by Chemfix as representative.

Samples of treated waste also collected for the long-term testing program established for the Chemfix demonstration (PRC SITE Team, 1989). This program was designed to determine the effect of aging on the strength, acid neutralization capacity, and leaching potential of the treated wastes.

4.7.4 Air Monitoring

To evaluate whether any reductions of PCBs in the treated waste could be attributed to volatilization during each test run, the concentration of PCBs in the ambient air in close proximity to and downwind of the Chemfix equipment was measured using a high-volume sampling device. Another sampling device was located upwind of the Chemfix equipment to measure the background concentration of PCBs in the air. The sampler consisted of a glass fiber filter and a polyurethane foam (PUF) sorbent cartridge, designed to sample ambient air at a rate of 200 to 280 liters per minute. The PCBs collected on both the filter and PUF cartridge were recovered by Soxhlet extraction and the extracts were analyzed for PCBs using gas chromatography with mass spectrometry detection.

4.7.5 Quality Control Procedures

As described in Section 4.4.4, the Chemfix weigh feeder used to determine the amounts of waste processed during each test run was calibrated in the field, using clean sand weighed by a commercial scale (Weight-Tronix). The commercial scale was also calibrated in the field, using calibration weights (1,000 lb) from the supplier. One plywood box containing clean sand was weighed on a calibrated commercial scale and the sand was fed through the Chemfix weight feeder. The two weights were then compared and a correction factor determined for the weigh feeder.

Quality control (QC) during sampling included the following steps:

- All sampling equipment was thoroughly cleaned before and after sampling of each source area.
- All sample containers were cleaned in accordance with specific sampling method requirements. Glass containers were obtained from I-Chem

Research, Inc. These containers were cleaned according to EPA protocols and were QC analyzed. Wax-coated cardboard molds that met the absorptivity, watertightness, and elongation requirements outlined in ASTM C470 were used to sample the reagent mixes and the treated wastes.

- All samples were preserved as required.
- Duplicate field samples were collected for at least 10 percent of the total samples collected.

An EPA designated contractor performed a field audit during the demonstration to ensure that all quality assurance/quality control (QA/QC) procedures were being followed. The audit found the sampling activities satisfactory.

4.8 ANALYTICAL PROCEDURES

The analyses were conducted in accordance with the sampling and analysis plan (PRC SITE Team, 1989). Chemical analyses were performed according to EPA SW-846 (U.S. EPA, 1986), EPA 600 (U.S. EPA, 1979), ASTM (ASTM, 1987), and ASA (Page, 1982) methods. Engineering and geotechnical tests were performed according to ASTM, TMSWC (Environment Canada/U.S. EPA, undated), and ASA methods. Table 4-4 is a list of the procedures used in the demonstration.

There were two minor deviations from the original sampling and analysis plan. First, the Standard Proctor Test was not performed because of the large particle size of the raw waste. The large particle size required a large test cylinder, which was not available at the laboratory. In addition, this test was not critical to the overall evaluation of the Chemfix demonstration.

Second, the acid neutralization capacity test method was changed. The original method (TMSWC 7: Acid Neutralization Capacity) using nitric acid was not strong enough to allow a complete titration of the treated waste samples to acidic pH. Therefore, an alternative method (U.S. EPA, 1988) using hydrochloric acid was used. In addition, the acid neutralization capacity test was not conducted for raw waste because the pH of raw waste was low, indicating there is no alkalinity in the raw waste.

Table 4-4

Analytical Procedures Used For the Chemfix Demonstration

Leaching Tests	Method
TCLP	Modified 40 CFR Part 268 (Federal Register, 1986)
ANS 16.1	Modified ANS 16.1
BET	Modified TMSWC-6 (Côte, 1988)
MEP	Modified EPA Method 1320
Chemical Tests	
pH	EPA Method 9045/9040
Eh	Modified EPA Method 9045
Electrical Conductivity	ASA-10-4.3
Acid Neutralization Capacity	TMSWC-7
Total Organic Carbon (TOC)	ASA 29-4.5.2
Humic Acid	ASA-30-4.2
Oil and Grease	EPA Method 414.2
Volatile Organic Compounds (VOCs), Semivolatile Organic Compounds (SVOCs), Metals, Polychlorinated Biphenyls (PCBs) and Pesticides, Dioxins, and Furans	EPA Method 8240 for VOCs EPA Method 8270 for SVOCs EPA Method 8080 for PCBs and Pesticides EPA Method 8280 for Dioxins and Furans EPA Methods 6010, 7060, 7421, 7740, 7841, 7470, 7471 for Metals
Lead Compounds	See Note a
Total Dissolved Solids (TDS)	EPA Method 160.1
PCB Dechlorination	EPA Methods 680 and 3540 (See Note b)

Table 4-4

Analytical Procedures Used For the Chemfix Demonstration (Continued)

Engineering/Geotechnical Tests	Method
Particle Size Analysis	ASTM D422
Water Content	Modified ASTM D2216/TMSWC-4
Bulk Density	ASA-13-2/TMSWC-2
Specific Gravity	ASTM D854
Wet/Dry Weathering Test	ASTM D4843-88 (Draft)
Freeze/Thaw Weathering Test	ASTM D4842-88 (Draft)
Unconfined Compressive Strength (UCS)	ASTM D1633
Immersion/UCS	Modified ASTM D1633/ASTM C39
Hydraulic Conductivity	EPA Draft Protocol (CSS-13)
In Situ Hydraulic Conductivity	ASTM D3385-75
Slump of Portland Cement Concrete	ASTM C143
Standard Proctor Test	ASTM D698
Petrographic Examination	ASTM C856

Notes:

a Lead compounds were determined by the method developed by Western Research Institute

b One of the two PCB dechlorination analyses were conducted using the procedures developed by RMC Environmental and Analytical Laboratories, Inc.

5.0 ANALYTICAL RESULTS

5.1 PURPOSE

Performance data were collected from the Chemfix solidification/stabilization process demonstration at the PESC site to evaluate the overall performance and cost of the Chemfix technology as it was applied to wastes from this hazardous waste site. The following sections describe the results in detail. The leach tests are discussed first and are followed by discussion of the results of the chemical tests, physical tests, petrographic analysis, PCB dechlorination test, air monitoring, and long-term tests. A discussion of the mass balance between raw and treated waste completes the chapter.

Appendix B contains summary tables of data from the analyses conducted for the demonstration.

5.2 LEACH TESTS

The toxicity characteristic leaching procedure (TCLP) and PCB and metal analyses of the extracts were performed on each of five samples of untreated waste from each test run. TCLP extracts from five samples of pretreatment waste from each area were analyzed to compare lead and copper concentrations after treatment and to determine percent reductions as a result of treatment. Additional leaching procedures were used to evaluate the chemical stability and leaching potential of the pretreatment and posttreatment wastes. These procedures included the multiple extraction procedure (MEP) and the American Nuclear Society Test 16.1 (ANS 16.1). ANS 16.1 was used only for the posttreatment waste products.

5.2.1 Toxicity Characteristic Leaching Procedure

The TCLP is used to evaluate a waste's potential for leaching contaminants when the waste is codisposed with municipal waste in a landfill. The material is ground to pass a 9.5-mm standard sieve. Generally, it is the basis for the Environmental Protection Agency's (EPA's) regulation of lead in solid waste under the Land Disposal Restrictions of the Resource Conservation and Recovery Act (RCRA). Because the TCLP is a regulatory test for RCRA hazardous wastes, it is likely to be considered to determine the success of future applications of the Chemfix technology to other wastes. The test was a focus of this demonstration. Tables B-1 through B-5 present a summary of lead, copper, and zinc concentrations in TCLP extracts of pretreatment and posttreatment waste samples from Areas A, C, E, and F and the reagent mix.

Overall, concentrations of lead, copper, zinc, and other metals were reduced substantially in TCLP extracts of posttreatment wastes compared to pretreatment wastes. PCBs were not found in TCLP extracts of pretreatment or posttreatment waste samples. PCBs and metals were not found in TCLP extracts of the reagent mix samples. The treated wastes were not analyzed for volatile organic compounds, semivolatile organic compounds, and dioxins because these contaminants were not found in the TCLP extract of the wastes during the preliminary round of sampling.

5.2.2 Reduction of TCLP-Extractable Lead, Copper, and Zinc

Treatment of wastes from Areas A, C, E, and F resulted in reduced levels of TCLP-extractable lead, copper, and zinc. Table 5-1 presents the percent reductions of mean TCLP-extractable lead, copper, and zinc. The results show that the application of the Chemfix technology resulted in significant reductions in the concentrations of those metals in the TCLP extracts of the wastes for each of the four areas of the sites.

Table 5-1

Mean Concentrations of Metals in Untreated and Treated Material from CHEMFIX Demonstration

	Mean Concentration In Untreated Wastes (Total, mg/kg)	Mean Concentration In TCLP From Untreated Waste (mg/L)	Mean Concentration In TCLP From Treated Waste (mg/L)	% Reduction In Mean TCLP Concentrations
Lead				
Area A	21,000	610	<0.50	99.9
Area C	140,000	880	2.5	99.7
Area E	92,000	740	47.0	94.6
Area F	11,000	390	0.10	99.9
Copper				
Area A	18,000	45	0.57	98.9
Area C	18,000	12	0.54	95.5
Area E	74,000	120	0.65	99.4
Area F	33,000	120	0.60	99.5
Zinc				
Area A	1,800	16	0.024	99.8
Area C	4,200	30	0.25	99.1
Area E	8,000	71	4.8	94.2
Area F	5,100	42	0.03	99.9

5.2.3 A Comparison of TCLP Results and Possible Regulatory Standards

This demonstration was designed to test the ability of the Chemfix process to meet potential regulatory standards under RCR4. The Land Disposal Restrictions are likely to be considered applicable or relevant and appropriate requirements for Superfund wastes treated with the Chemfix process. Several land ban standards could apply to the waste treated at this demonstration. The demonstration plan (PRC Site Team 1989) identified the standard for lead in electroplating wastes as appropriate to consider. The standard requires RCRA listed plating wastes (sludges) to have lead concentrations of 0.51 mg/L or less in the TCLP extracts before the material can be land disposed. Because soil is often more difficult to treat than sludges, an arbitrary soil treatment standard of 5.0 mg/L is also considered.

Under current EPA Superfund policy, the land ban standard for electroplating waste is likely to be too stringent for the soils found at the PESC site. The soil at that site is a candidate for a treatability variance under RCRA Section 268.44. Alternative treatment levels have been set for contaminants found in soil and debris at Superfund sites. For wastes with initial concentrations of lead in TCLP extracts greater than 300 ppm (soils at the PESC site had concentrations over this level), the treatability variance under the Land Disposal Restrictions requires treatment to achieve 99 to 99.9 percent reduction in the concentrations of lead in the TCLP extracts. (Superfund LDR Guide #6A, July 1989).

A review of the data in Table 5-1 shows that the Chemfix process achieved at least 99 percent reduction in mean lead concentrations for wastes from three of the four areas of the site.

Table 5-2 presents comparisons of results from the TCLP extracts from all samples to three standards. The first standard to which the results were compared is the standard for electroplating under the Land Disposal Restrictions, which was discussed in the demonstration plan for this work. That standard is 0.51 mg/L lead. The second standard used for comparison is 5.0 mg/l lead in the TCLP extract. The third standard is 99 percent reduction of the concentration of lead in the TCLP extract. This is the standard discussed in EPA's interim policy for soil and debris.

Table 5-2 presents the percentage of the total number of samples that met each of the standards. This comparison is consistent with both the Land Disposal Restrictions and the definition of a characteristic waste. Both regulations compare an individual representative sample to a standard and determine pass/failure of the waste based on that one sample. Therefore, from Table 3-3, 70 percent of the samples passed the soil standard chosen for the demonstration for lead (5.0 mg/L) and 30 percent did not.

The sampling and analysis plan for this demonstration (PRC SITE Team, 1989) suggested using the Student T test to compare the results of the replicate analyses with the regulatory standards for the treated wastes. Because the regulations that are likely to apply do not use statistical analyses of the results to determine compliance with the standards, the Student T test may not be an appropriate tool for comparing these results to the standards. In addition, the extreme variability of the results in this test makes application of the Student T less valuable than if the data were more closely grouped. For both of these reasons, the Student T test was not used to analyze the data for this test.

Table 5-2

A Comparison of TCLP Results for Lead With Three Potential Standards, Includes Data From All Areas

Standard	% of Samples Passing the Standard
1. 0.51 mg/L	65%
2. 5.0 mg/L	70%
4. 99% Reduction	70%

5.2.4 American Nuclear Society Test 16.1

The ANS 16.1 test is used by the nuclear industry to identify the mechanisms that control leaching and indicate the amount of possible leaching from a monolithic solid. This dynamic leaching procedure consists of sequentially leaching a cylindrical solidified waste sample in distilled water for periods ranging from 2 hours to 43 days. This leaching procedure is used to simulate contact of the solidified wastes with rapidly flowing ground water. Because the material is not ground as part of the test, as it is in other leaching or extraction tests, ANS 16.1 provides information on the structural ability of the treated material as a solid to contain contaminants.

Several facts should be considered in reviewing the results of this test. First, the test is normally conducted on the monolith-like solids generated by the solidification/stabilization projects in the nuclear industry. Although for this demonstration the Chemfix process generated a monolithic-like solid, it does not always result in such a solid, depending on the application. The results of this test may not be comparable to other test results and may have limited applicability to other uses of the Chemfix technology. It was not performed on the untreated wastes because they were friable soil.

The mean leachate lead concentrations per extract increased from 0.2 to 2.3 mg/L as the test progressed from an initial contact period of 2 hours to one of 43 days. The mean leachate copper per extract concentrations increased from 0.05 to 0.28 over this time. A concurrent increase in the mean leachate pH values occurred and ranged from 9.9 to 11.0. Tables B-6 through B-15 show a summary of results for the 90-day ANS 16.1 leaching test of posttreatment waste from Area C.

The leachability index was calculated from the results for lead, copper, arsenic, and zinc.

The leachability index is defined as:

$$L_i = \Sigma \log (1/D)$$

where D is the effective diffusivity. The values of the leachability indices are as follows:

Lead - $L_i = 14.2$
Copper - $L_i = 14.0$
Arsenic - $L_i = 12.6$
Zinc - $L_i = 14.2$

These values successfully exceed the Nuclear Regulatory Commission's leachability index standard of 6 by several orders of magnitude. However, the standard for this index is not sufficient to guarantee the products of the process are protective of human health and the environment if they are placed in a landfill. The fluxes from the solids, shown in Table 5-3 with the leachability indices, may be used in a site-specific ground water flow model to ensure adequate protection of public health and the environment.

5.2.5 Multiple Extraction Procedure

The MEP was performed on pretreatment and posttreatment waste samples from Area C. This procedure was used to determine the leaching properties of the waste using the RCRA extraction procedure (EP) followed by nine sequential extractions with acidified distilled water. Tables B-16 through B-25 summarize results of this procedure.

This test was included as part of the demonstration because the worst case results of the test have been used in EPA's models for delisting RCRA listed hazardous wastes. Those models assume a specific disposal facility scenario and evaluate the health effects to a receptor at that facility from the leachate. The scenario results in dilution of the leachate ranging from 6:1 to 50:1 before it reaches the receptor.

TABLE 5-3. FLUX AND LEACHABILITY INDEX FOR SELECTED METALS FROM THE ANS 16.1 TEST

Leachate	Arsenic		Copper		Lead		Zinc	
	Flux ($mg/cm^2/s$) x E+9	Leachability Index	Flux ($mg/cm^2/s$) x E+9	Leachability Index	Flux ($mg/cm^2/s$) x E+9	Leachability Index	Flux ($mg/cm^2/s$) x E+9	Leachability Index
2 Hours	1.237	11.9	69	13.4	247	13.5	14.8	13.3
7 Hours	0.396	12.1	22	13.6	160	13.0	5.9	13.3
24 Hours	0.234	12.0	9.9	13.8	97	13.0	1.6	14.0
48 Hours	0.154	12.0	6.5	13.8	76	12.8	1.0	14.0
72 Hours	0.104	12.2	3.2	14.2	41	13.2	1.2	13.7
96 Hours	0.028	13.2	2.4	14.4	28	13.4	0.56	14.2
120 Hours	0.022	13.3	1.6	14.6	22	13.5	0.44	14.3
19 Days	0.020	12.9	1.9	14.0	19	13.1	0.08	15.3
47 Days	0.023	12.3	0.92	14.1	11	13.1	0.04	15.4
90 Days	0.004	13.6	0.59	14.3	4.8	13.6	0.10	14.4
	Mean	12.6	Mean	14.0	Mean	13.2	Mean	14.2
	Std. Dev.	0.63	Std. Dev.	0.37	Std. Dev.	0.27	Std. Dev.	0.72

The data from this test give several important pieces of information. First, the initial extraction uses the same procedure as the EP toxicity test. The results from that extraction can be used to determine whether the waste is a characteristic waste. Second, the data from the nine sequential extractions provide information on the trend of leaching from the waste. Finally, the test shows the total leaching from the waste under the conditions of the test for comparison with other products.

Lead, copper, and zinc were found in first extraction of the MEP and acidified water extractions of pretreatment and posttreatment waste samples. The mean lead concentrations in the original (EP toxicity extraction) were 663 and 332 mg/L for pretreatment and posttreatment waste, respectively. In addition, the mean concentrations of lead increased in the last two replicates over time in some replicates. This increase suggests that some samples of the treated material would be expected to leach as time elapses after disposal if buffering capacity is decreased and structural integrity is lessened.

Figure 5-1 presents the mean concentration of lead found in each of the MEP extractions from the treated wastes.

5.2.6 Batch Extraction Test

The Batch Extraction Test was run on samples of treated and untreated waste. The results of this test are shown in Tables B-26 through B-28. Opinions of experts in the solidification/stabilization field vary as to the usefulness of this test in representing the leachability of metals from stabilized material. Therefore, no conclusions were drawn in this report from this data.

5.2.7 Interpretation of Test Results From Several Leach Tests

For this demonstration, two types of leaching and extraction tests were used to analyze the samples. The first type of test includes those used for regulatory purposes, the TCLP and MEP, and the result from these tests have been compared to existing standards, as discussed above. The second type of test includes technical tests, such as the ANS 16.1 and the BET, that were conducted to provide information on metals concentrations leaching from the stabilized wastes for use in site-specific ground-water models. The results of these ground-water models should be considered to ensure the Chemfix products are protective of human health and the environment before the technology is selected for a specific site. It is important to note that the TCLP, BET, and MEP involve grinding of the treated solid material which may not occur in the field.

Because of variations in testing procedures, it is impossible to directly compare the results of the four leach tests used for this project. However, the information provided by each test can be used to draw conclusions regarding the treated product from the Chemfix process.

The leach test results from TCLP and MEP were evaluated by plotting lead concentrations against the final pH of extracts and leachates from the pretreatment and posttreatment waste samples from all areas. These relationships are displayed in Figure 5-2 and Figure 5-3. These figures closely resemble the normal shape of the solubility curve for lead, with the concentration of lead in the extracts or leachates decreasing as the pH moves above 4. The concentration is generally less than 1.0 mg/L between 8 and 10 pH units and increases as the pH climbs above 10. The figure indicates that pH is a major factor controlling the leach test results.

5.3 CHEMICAL TESTS

Tables B-29 through B-33 summarize the results of the chemical tests performed on the pretreatment and posttreatment waste samples and the reagent mix solids. Chemical characteristics determined for the wastes include pH, Eh, electrical conductivity (EC), total

Figure 5-1 Mean Concentration of Lead in MEP Extract From Chemfix-Treated Waste From Area C

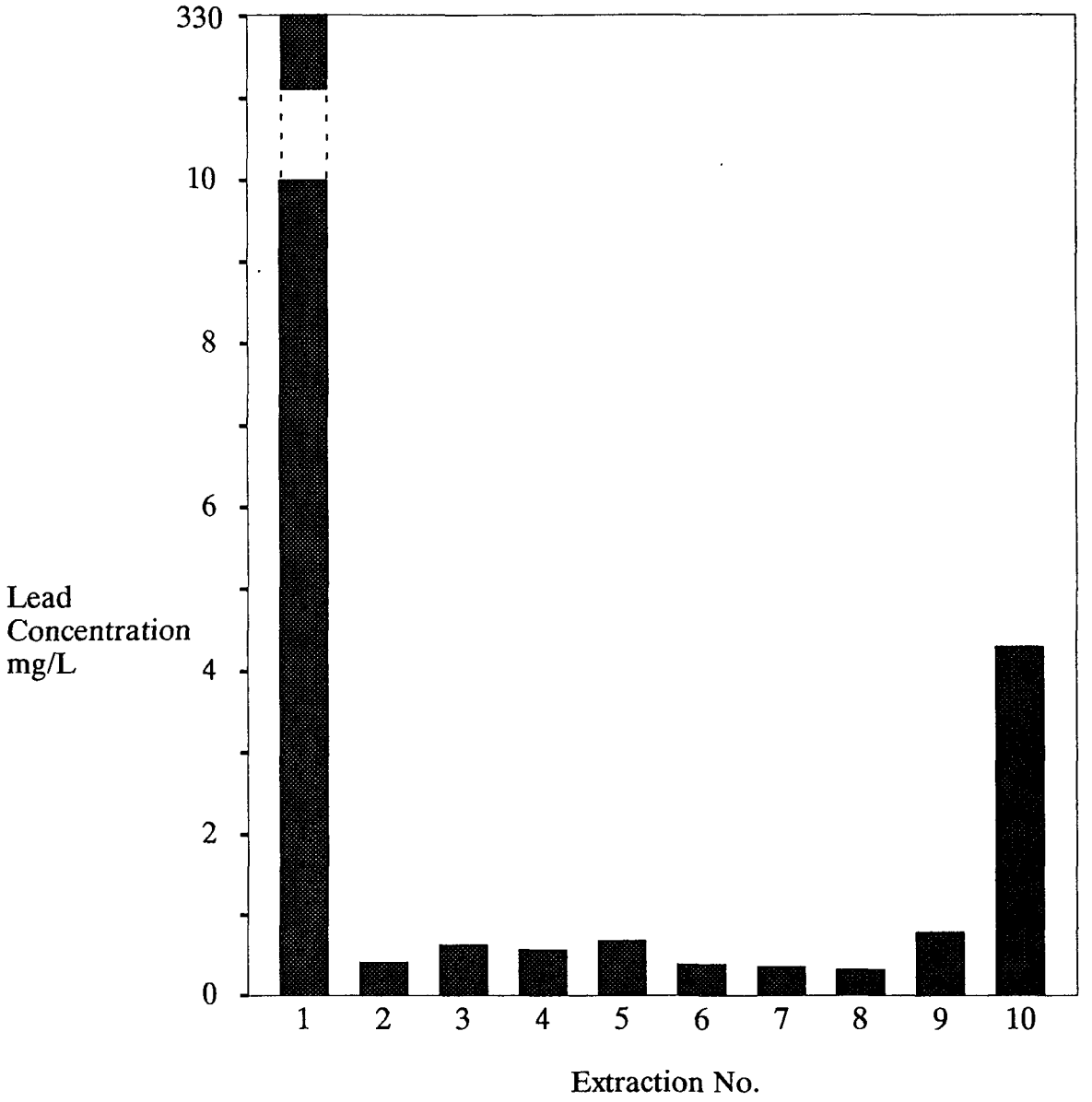


Figure 5-2 Summary of Extraction Data for Untreated Wastes TCLP and MEP Data From All Areas

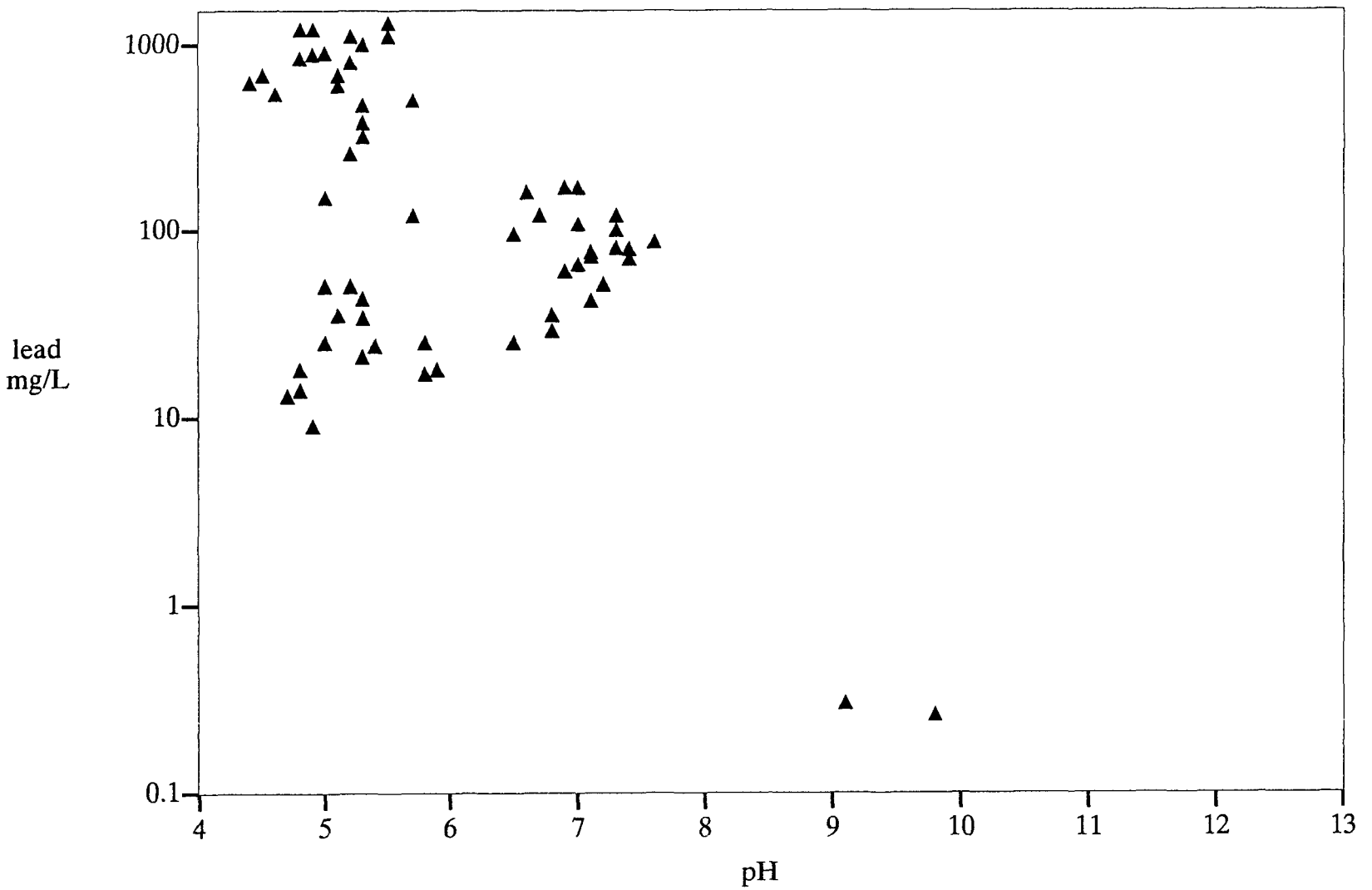
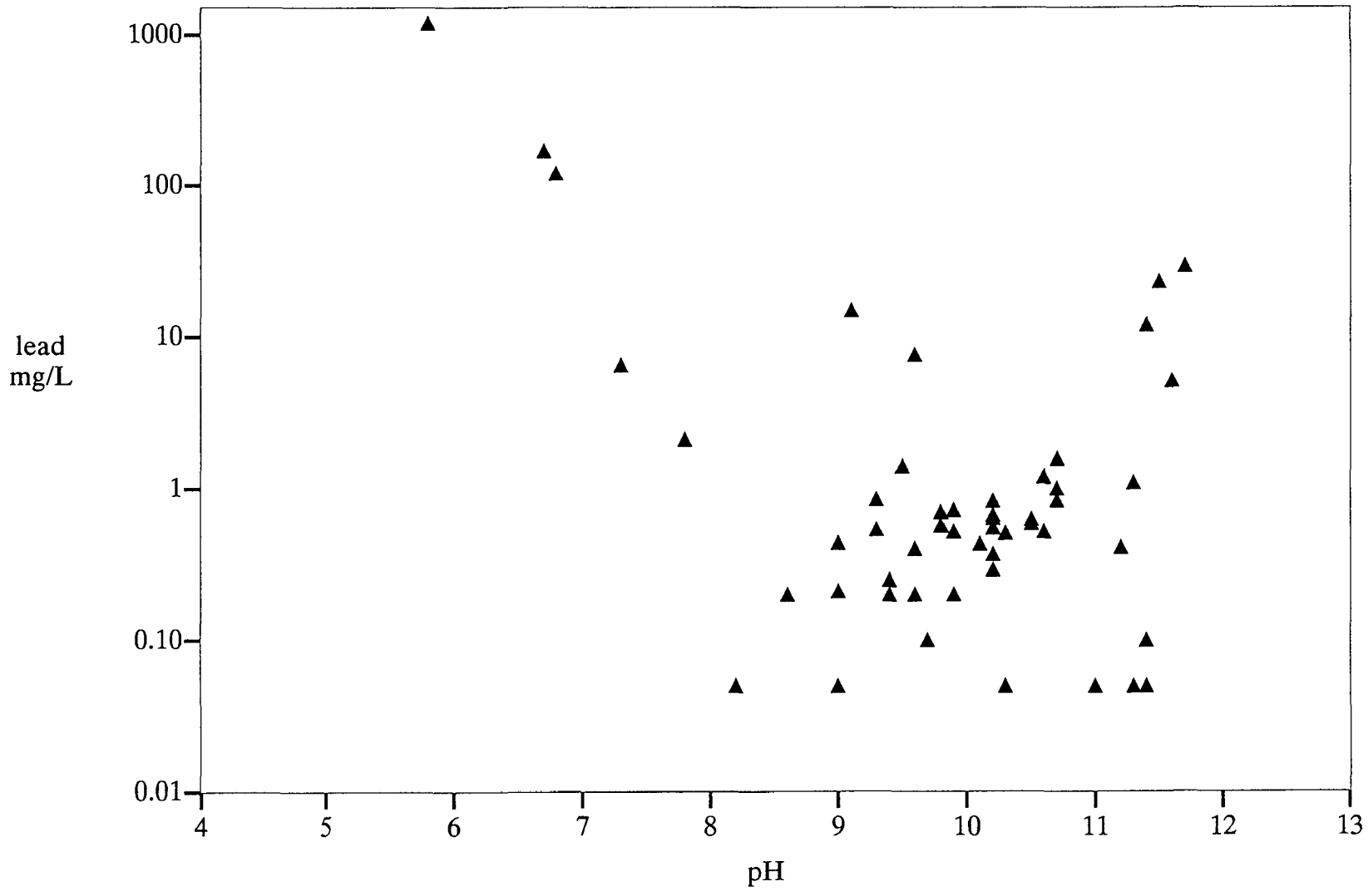


Figure 5–3 Summary of Extraction Data for Treated Wastes
TCLP and MEP Data From All Areas



organic carbon (TOC), acid neutralization capacity (ANC), oil and grease, metals, volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), pesticides, PCBs, lead compounds, and humic acid. These results are summarized below.

5.3.1 pH

The pH of the pretreatment and posttreatment wastes and the reagent mix was determined by EPA Method 9045. The pH of pretreatment wastes for each of the areas ranged from 6.5 in Area C to 7.2 in Area 4. After treatment the pH was much higher, ranging from 11.0 in Area E to 11.8 in Area F.

The increase in pH observed is consistent with the alkalinity associated with the cementitious additives in the solidification reagents. The pH of the reagent mixture ranged from 11.6 to 11.9 pH units.

5.3.2 Eh

The Eh is a measure of the reduction/oxidation potential of the material. EPA Method 9045 was used to determine Eh in waste and water slurries. The Eh was determined for the pretreatment and posttreatment wastes and the reagent mix with an Eh electrode on the waste and water slurries prepared for the pH test. The Eh of the pretreatment wastes ranged from 140 mv in Area A to about 280 mv in Areas C and E. The Eh values of posttreatment wastes and the reagent mix ranged from 24 to 53 mv. This decrease in the reduction/oxidation potential indicates a less oxidizing environment as a result of treatment.

5.3.3 Electrical Conductivity

The EC of the pretreatment and posttreatment wastes and the reagent mix was determined with a conductivity cell on waste and water slurries prepared for the determination of pH by ASA Method 10-4.4. The EC of the pretreatment wastes ranged from 83 µmhos/cm in Area A to about 340 µmhos/cm in Area F. The posttreatment wastes and the reagent mix had ECs ranging from 2,500 µmhos/cm in Area E to 4,600 µmhos/cm in Area 4.

This increase in electrical conductivity with treatment indicates an increase in the number of ions in solution. These ions are probably the result of the addition of soluble compounds in the reagent mix or the solubilization of waste components after treatment. It should be noted that soluble compounds from the reagent mix may not be toxic.

5.3.4 Total Organic Carbon

TOC content of the pretreatment and posttreatment wastes was determined by the Walkley-Black Procedure described in ASA Method 29-4.5.2. The organic carbon is contained in the soil organic fraction and consists of the cells of microorganisms, plant and animal residues at various stages of decomposition, stable humus synthesized from residues, and highly carbonized compounds such as graphite, charcoal, coal, and organic contaminants. The TOC found in contaminated soil from the PESC site can be attributed partially to the high oil and grease content. This test was included in the demonstration to both characterize the wastes before and after treatment and provide information on possible sources of interference if the chemistry did not work. In general, high concentrations (greater than 25 percent) of TOC or oil and grease in raw wastes will often interfere with most solidification/stabilization processes.

The concentration of TOC observed in the wastes did not change significantly during treatment for any of the areas analyzed. The pretreatment and posttreatment wastes from Area A contained approximately 4.2 weight percent TOC. The pretreatment waste from Area C contained 4.6 weight percent TOC while the posttreatment waste contained 4.9 weight percent

TOC. The pretreatment and posttreatment wastes from Area E contained 7.9 and 7.4 weight percent TOC, respectively. The pretreatment and posttreatment wastes from Area F contained approximately 4.2 weight percent TOC.

These concentrations do not reflect any analysis of or adjustment for dilution of the waste material by the Chemfix reagents. Thus, the decreases in concentration may be the result of either the variability of the original waste or dilution of the material. However, the Chemfix reagents were analyzed for TOC and no detectable concentrations were found. Therefore, any increase in the concentration of TOC between pretreatment and posttreatment reflects the variability in the original waste, not addition of TOC with the Chemfix reagents.

5.3.5 Acid Neutralization Capacity

The ANC of the pretreatment and posttreatment wastes was determined by the method of Sobek. The pretreatment soils were nonalkaline. The ANC of posttreatment wastes ranged from 2.8 meq/g in Area A to 4.9 meq/g Area C. The ANC of the posttreatment samples reflects the amount of alkaline reagents added to the wastes in the treatment process (Sobek, 1978). This data suggests that weak acid attack on the matrix will be limited by the alkalinity of the reagents.

5.3.6 Oil and Grease

The oil and grease content of the pretreatment and posttreatment wastes was determined by a sonication extraction of the soil using a modified EPA Method 3550 followed by EPA Method 414.2. The posttreatment wastes from Area F contained more oil and grease than the pretreatment wastes. In this case the posttreatment and pretreatment wastes contained mean oil and grease content of 0.4 and 1.4 weight percent, respectively. The mean oil and grease content of Area E was 7.5 weight percent in the pretreatment wastes and 6.5 weight percent in the posttreatment wastes. Oil and grease levels in samples from Areas A and C were the same before and after treatment.

Analysis of the Chemfix reagent mix shows very small concentrations of oil and grease. Any apparent increase in the concentrations after treatment is likely to be the result of variability of the wastes.

5.3.7 Metals

Several EPA methods were used to determine the concentration of extractable metals in the pretreatment and posttreatment wastes. The data show significant variability in the concentrations of the metals of concern in the untreated wastes. The mean concentrations were 140,000 mg/kg for Area C, 21,000 mg/kg for Area A, 92,000 mg/kg for Area E, and 11,000 mg/kg for Area F. The relative standard deviations for concentrations of lead in these areas were 9 percent, 41 percent, 27 percent, and 78 percent, respectively, indicating that Area F had the most variation in the lead concentration in the untreated wastes and Area C the least. The concentrations of copper and zinc showed similar variability.

After treatment, the concentrations of the metals of concern also showed significant variability. Posttreatment samples for Area A had a mean concentration of lead of 21,000 mg/kg. Similarly, Area C had 52,000 mg/kg; Area E had 38,000 mg/kg; and Area F had 9,900 mg/kg in the posttreatment samples.

The Chemfix process is intended to immobilize the metals of concern; it does not remove or destroy the metals in the original matrix. Any apparent decrease in concentrations in the solids between the pretreated and treated wastes may be attributed to the variability of the original wastes or the dilution of the material with the reagents added during treatment.

Similarly, any apparent increase in the concentrations of the metals of concern is most likely attributed to variability of the wastes, not necessarily to the reagents added. The reagent mix was tested and found to contain high concentrations of calcium, aluminum, and sodium as expected for cementitious material and other reagents used by Chemfix. However, the reagent mix contained low concentrations of lead, copper, and zinc.

5.3.8 Volatile Organic Compounds

The pretreatment and posttreatment wastes were analyzed for VOCs by EPA Method 8240. VOCs were not detected in the pretreatment wastes from Areas A, C, and E. The pretreatment Area F samples contained approximately 0.8 mg/kg tetrachloroethylene. VOCs were not detected in any of the posttreatment waste samples. The slight decrease in concentrations of VOCs indicated in Area F are likely to be the result of volatilization during treatment, dilution, sample variability, chemical encapsulation, or a combination of several or all of these factors.

5.3.9 Semivolatile Organic Compounds

The pretreatment and posttreatment wastes were analyzed for SVOCs by EPA Method 8270. The pretreatment Area A samples contained detectable quantities of benzo(b)fluoranthene (2 mg/kg) and benzo(k)fluoranthene (2 mg/kg). Posttreatment samples from Area A contained about 4 mg/kg benzidine. SVOCs were not detected in the pretreatment Area C samples. Benzo(b)fluoranthene (7 mg/kg) and benzo(k)fluoranthene (7 mg/kg) were detected in the pretreatment Area E wastes. The posttreatment samples from Area E contained about 18 mg/kg bis(2-ethylhexyl)phthalate.

The samples of both pretreatment and posttreatment material from Area F contained similar levels of benzo(a)pyrene (3 mg/kg), benzo(b)fluoranthene (6 mg/kg), benzo(g,h,i)perylene (3 mg/kg), benzo(k)fluoranthene (6 mg/kg), chrysene (3 mg/kg), indeno(1,2,3-c,d)pyrene (3 mg/kg), pyrene (4 mg/kg), and 1,2,4-trichlorobenzene (7 mg/kg). This solidification/stabilization technique did not reduce the levels of these SVOCs during the treatment process, indicating that no significant volatilization occurred during treatment under the atmospheric conditions of the demonstration. Further, the results suggest that SVOCs are not strongly absorbed onto the treatment matrix.

5.3.10 Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans

EPA Method 8280 was used to determine the concentration of PCDDs and PCDFs in the pretreatment wastes from Areas C and F. Tetra-, penta-, and hexa-PCDD congeners were not detected in the pretreatment wastes from Areas C and F. Heptachlorinated dibenzo-p-dioxins were found at approximately 7 μg/kg in the wastes from Area C and at approximately 14 μg/kg in Area F. Area C contained approximately 10 μg/kg octachlorinated dibenzo-p-dioxin (OCDD). Area F contained approximately 14 μg/kg OCDD.

Hexa-, hepta-, and octa-PCDF congeners were found in the pretreatment wastes from Area C at concentrations of approximately 10, 19, and 5 μg/kg, respectively. Penta- through octa-PCDF congeners were found in the pretreatment wastes from Area F at the following concentrations: 6 μg/kg PeCDFs; 35 μg/kg HxCDFs; 23 μg/kg HpCDFs; and 12 μg/kg OCDD.

The treated material was not analyzed for dioxin.

5.3.11 Polychlorinated Biphenyls

The pretreatment and posttreatment wastes were analyzed for PCBs by EPA Method 8080. Aroclor 1016 and Aroclor 1260 were found in the pretreatment and posttreatment wastes from all four areas. The pretreatment samples from Area A contained approximately 15 and 120 mg/kg of Aroclor 1016 and Aroclor 1260, respectively. The posttreatment samples from Area A

contained approximately 24 and 95 mg/kg of Aroclor 1016 and Aroclor 1260, respectively. The pretreatment wastes from Area C contained approximately 80 and 180 mg/kg of Aroclor 1016 and Aroclor 1260, respectively. The posttreatment samples from Area C contained approximately 50 mg/kg of Aroclor 1016 and 130 mg/kg of Aroclor 1260.

The pretreatment samples from Area E contained approximately 260 mg/kg of Aroclor 1016 and Aroclor 1260. The posttreatment samples from Area E contained 170 to 190 mg/kg of each of these Aroclors. The pretreatment Area F samples contained approximately 17 mg/kg Aroclor 1016 and 300 mg/kg Aroclor 1260. The concentrations of these Aroclors in the posttreatment samples from Area F are 13 and 190 mg/kg for 1016 and 1260, respectively.

The differences between the concentrations in the pretreatment and posttreatment samples are likely to be the result of variations in the waste material and dilution with the reagents during treatment.

5.3.12 Lead Compounds

An analysis of three samples of raw waste was conducted to determine types and quantities of the lead compounds found in the waste. The method uses X-ray diffraction (XRD) procedures to identify lead phases. Semiquantification is possible by comparing integrated peak areas to reference standards. The lead phases are verified by scanning electron microscopy/ energy dispersive X-ray spectrometry (SEM/EDX).

Mineralogical analysis of the three samples revealed that there was very little difference between them. The samples differed only slightly in the peak intensities, which in turn can be interpreted as a slight difference in abundances. Four different lead materials could be identified in the samples. Metallic lead was by far the most abundant, with cerussite ($PbCO_3$) next in abundance. Litharge (PbO) and anglesite ($PbSO_4$) were also present in all three samples, but in slightly variable quantities and only at relatively minor abundances. Lead speciation controls the solubility of the metal.

SEM/EDX verified the results obtained from XRD. From detailed examination of the samples, it was apparent that the very large metallic lead particles were undergoing alteration to other lead compounds, primarily cerussite in the natural environment (not due to treatment). Some particles had been totally altered into the lead carbonate mineral.

5.3.13 Humic Acid

The humic acid content of the pretreatment wastes was determined by ASA Method 30-4.2. The mean humic acid concentration in the pretreatment wastes from Area A was 5.2 percent by weight. Pretreatment wastes from Area E contained 2.8 percent by weight humic acid. A humic acid concentration of approximately 1.0 percent by weight was observed in the pretreatment wastes from Areas C and F. Part of these values may be attributed to oil and grease, which this analytical method may detect as well as humic acid.

5.4 PHYSICAL TESTS

Physical tests performed on the pretreatment and posttreatment wastes included particle size distribution, water content, bulk density, specific gravity, hydraulic conductivity, UCS, immersion UCS, wet/dry weathering, freeze/thaw weathering, and slump tests. Tables B-29 through B-33 summarize the results for particle size distribution, water content, and specific gravity. These results are discussed in the following sections. Data from the UCS from Area C samples, immersion UCS, wet/dry weathering, and freeze/thaw weathering are presented in Tables B-34 through B-39.

5.4.1 Particle Size Distribution

The particle size distribution of the pretreatment soils was determined by ASTM D422-64. Generally, these curves show the particle size distributions are similar for all the areas of the site although Area F waste had more fine particles. The mean particle size for the pretreatment wastes ranged from 0.76 mm in Area F to 6.7 mm in Area C. Particle size was not determined for the posttreatment wastes because they were solid blocks.

This particle size range is representative of the pretreatment wastes that were screened to pass a 1-inch sieve. Approximately 40 percent of the pretreatment wastes were larger than 1-inch and were not included in the particle size analysis. This estimate is based on a viewer's judgment of the relative size of the waste piles, before and after sieving.

The particle size distribution is important for several reasons. First, it is important in characterizing the site and establishing a baseline description of the waste. Second, the particle size determines whether the waste may be treated with the Chemfix process without any pretreatment. If the particles are larger than 1 inch, the waste must be pretreated by pulverizing the large particles prior to treatment or separating the larger particles for application of another treatment technology, such as soil washing. Finally, data on particle size are helpful in the selection of the type of mixer.

5.4.2 Water Content

The water content of the pretreatment waste was determined by ASTM D2216-80. The water content of the posttreatment wastes and the reagent mix was determined by TMSWC-4. (Test Methods for Solidified Waste Characterization). The posttreatment samples were cured on-site for 2 days before transport to the lab for analysis. The water content was determined within 2 weeks of the samples arrival in the lab.

The water content of the pretreatment wastes from Areas A, C, E, and F measured 17, 12, 19, and 31 wet weight percent, respectively. These results are reported in wet weight percent (the weight of water divided by the weight of the total wet sample) because the protocol for the treated material reports the results in this fashion. It is likely that Area F had a higher moisture content because wastes from that area were ash with a higher fines content. After the solidification treatment, these wastes contained 16, 13, 14, and 19 wet weight percent water, respectively. As shown, the water content of Areas A, C, and E wastes remained essentially constant after the solidification treatment, while the water content of Area F waste was reduced. The reagent mix (liquid and solid reagents) had a water content of 8.0 wet weight percent.

5.4.3 Bulk Density

The bulk densities of the pretreatment wastes were to be determined in-situ using ASA Method 13-2, as wet-weight bulk density measurement. The bulk density of the material before and after treatment is important in the materials balance analysis to determine (1) the dilution of the contaminants that may be expected due to the addition of the reagents and (2) the expansion in the volume of the material that may be attributed to the treatment process. The bulk density is also used in the calculation of porosity discussed in Section 5.5.

Because of the high rock content of the contaminated soils, the sampling crew was unable to drive the Shelby tubes into the ground far enough to obtain usable samples for in situ bulk density tests. Instead, two sets of analyses were conducted to determine the bulk densities of the untreated wastes. The first set of analyses were field tests using uncompacted, excavated material that was sieved to pass through a 1-inch screen. The second set of analyses were conducted in the laboratory where the excavated, sieved samples were compacted. The samples were compacted with a 5.5-lb tamper dropped 12 inches 25 times for each lift (ASTM D698-78). There were three lifts per mold. Table 5-4 shows the results of both these analyses as well as the bulk densities for the treated material. As can be seen, the compaction in the lab resulted in higher bulk density readings.

Table 5-4

Bulk Density of Untreated and Treated Waste

	Untreated Waste		Treated Waste
	Field Analysis	Lab Analysis	
Area A	1.4 g/cm^3	2.0 g/cm^3	1.9 g/cm^3
Area C	1.5 g/cm^3	2.5 g/cm^3	2.0 g/cm^3
Area E	1.4 g/cm^3	2.2 g/cm^3	1.9 g/cm^3
Area F	1.4 g/cm^3	2.0 g/cm^3	1.6 g/cm^3

The wet-weight bulk densities of the posttreatment wastes were determined by TMSWC-2. Bulk densities for the posttreatment samples ranged from 1.6 to 2.0 g/cm^4.

5.4.4 Specific Gravity

The specific gravities of the pretreatment wastes were determined by ASTM D854. This analysis is necessary for the calculation of the porosity of the material, before and after treatment. The specific gravities of the pretreatment wastes from Areas A, E, and F were all 2.7. The specific gravity of the pretreatment waste from Area C was 4.1.

The specific gravities or true density of the posttreatment wastes were determined by two methodologies, TMSWC-5A and TMSWC-5B. The results of the first method are reported in Tables B-29 to B-32. These results are somewhat suspect because some components of the matrix floated to the surface during the volume displacement test using water. To correct for this difficulty, the second procedure, using a gas displacement method, was used.

	Specific Gravity TMSWC-5A	"True Density" TMSWC-5B
Area A	1.1	2.4
Area C	0.9	2.7
Area E	1.1	2.4
Area F	0.8	2.6

The true density results are used to calculate the porosity of the material.

5.4.5 Hydraulic Conductivity

The in-situ hydraulic conductivity of the pretreated waste from Area C was not determined by ASTM D3385 because of the high rock content of the waste soil. The screened pretreatment soils were compacted for the bulk density measurement described above, and the hydraulic conductivity of the sample was determined using CSS-13, a draft EPA protocol. This test measures the saturated hydraulic conductivity. The hydraulic conductivity of three replicate samples from Area C ranged from 2.4×10^{-6} to 2.7×10^{-4} cm/sec.

It is important to note that these values do not represent in-situ hydraulic conductivity and should not be used to determine whether the treated product will have less permeability than the adjoining soil if it is disposed of on-site.

The hydraulic conductivity of the treated waste from Area C was determined using CSS-14. The hydraulic conductivity of three replicate posttreatment samples from Area C ranged

from 4.6 x 10^{-7} to 1.2 x 10^{-6} cm/sec. Conductivities in the order of 10^{-6} or 10^{-7} cm/sec are generally considered acceptable for clay liners and caps for landfills.

5.4.6 Unconfined Compressive Strength

UCS determinations were conducted for molded samples of solidified waste from Area C according to ASTM D-1634. UCS was measured on nine sets of treated samples that had aged for 14, 21, and 28 days. Each of the nine sample sets represents the product from the demonstration at a specific time during the treatment process. For example, if the material from Area C took 13 minutes for treatment, the nine sets of samples may be the product taken from the discharge part of the process unit at 1 minute, 2 minutes, ..., and 9 minutes into the treatment process. Table B-34 presents the UCS for each of the nine sets of samples at 14, 21, and 28 days.

Each box of samples was cured on the site for 2 days prior to shipment to the lab for analysis. The curing conditions were not ideal because it was wet and cold. They modeled the likely curing conditions expected in a field application of the Chemfix technology, not the ideal curing conditions for a cementitious product.

The 14-day UCS measurements ranged from 243 psi for the first box to 55 psi for the seventh box. The sample from the sixth box broke when the cardboard mold was removed, so it had no measurable UCS, although it can be assumed to be low. The 21-day UCS values ranged from 298 psi in the second box to 52 psi in the seventh box. The 28-day UCS values ranged from 307 psi in the first box to 27 psi in the ninth box. The mean UCS for each test period was 131 psi for day 14, 136 psi for day 21, and 143 psi for day 28. Figure 5-4 shows the results of the UCS tests.

It should be noted that the results from the UCS tests are subject to several sources of variability. First, the waste from the PESC site is variable. Second, the sampling procedures are somewhat variable, for example, the procedures used for molding the cylinders for the test and the curing conditions may vary. Third, the test itself introduces some variability. Finally, the Chemfix treatment process may introduce variability if the waste matrix and reagents are not delivered at a consistent rate or they are not well mixed during treatment.

The results of this test indicate the UCS of the products of the Chemfix process generally meets the EPA guidance of 50 psi for placement in a landfill. These results also suggest that the UCS value does not change much with additional curing after 14 days. In fact, Chemfix staff indicate that their experience with their product has been that it sets up in a very short time, within 24 to 72 hours. The results also show that there was significant variability between the sample sets taken at different times during the treatment of the wastes during the demonstration.

The results show that the UCS of the samples taken 1 minute into the process are significantly different from the UCS of samples taken 9 minutes into the treatment process. Figure 5-5 shows this drift in UCS of the products indicating that variability.

5.4.7 Immersion UCS

UCS has two components. Part of the strength of a cured product is the result of the drying of the particles in a matrix and part of the strength comes from actual adhesion between particles. The immersion UCS test distinguishes between these components. If there is no reduction in strength after prolonged immersion in water, the product demonstrates real adhesion between particles. There is no generally accepted standard for this test but it is included in this demonstration for comparison with the UCS.

Eighteen posttreatment samples from Area C were immersed in water. Six cores, one from each of the first sampling boxes, were removed at 30, 60, and 90 days after immersion. The UCS of each of these cores was determined by ASTM D1634. The 30-day immersion UCS

Figure 5-4 Mean Unconfined Compressive Strength for Chemfix-Treated Waste From Area C

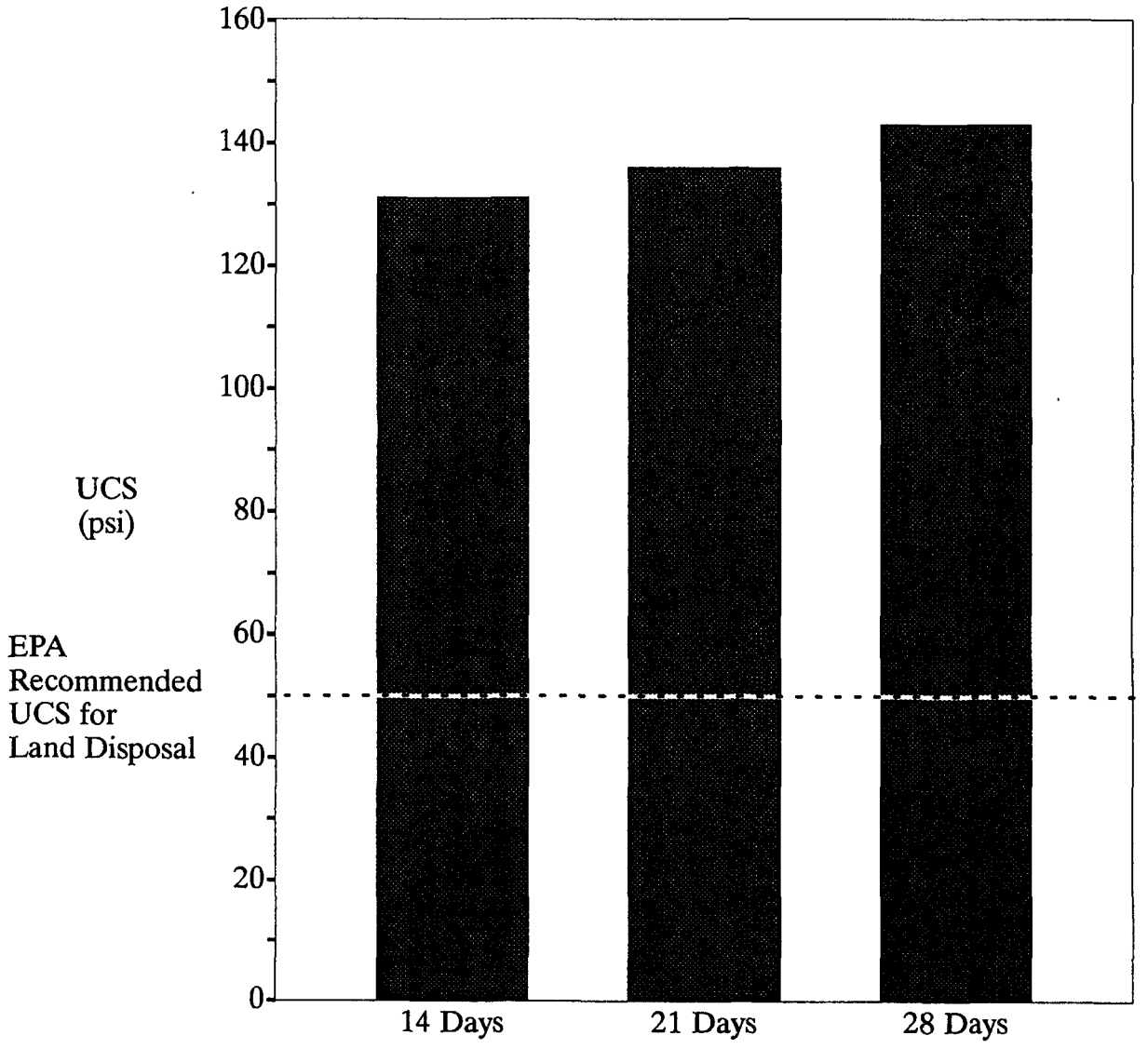
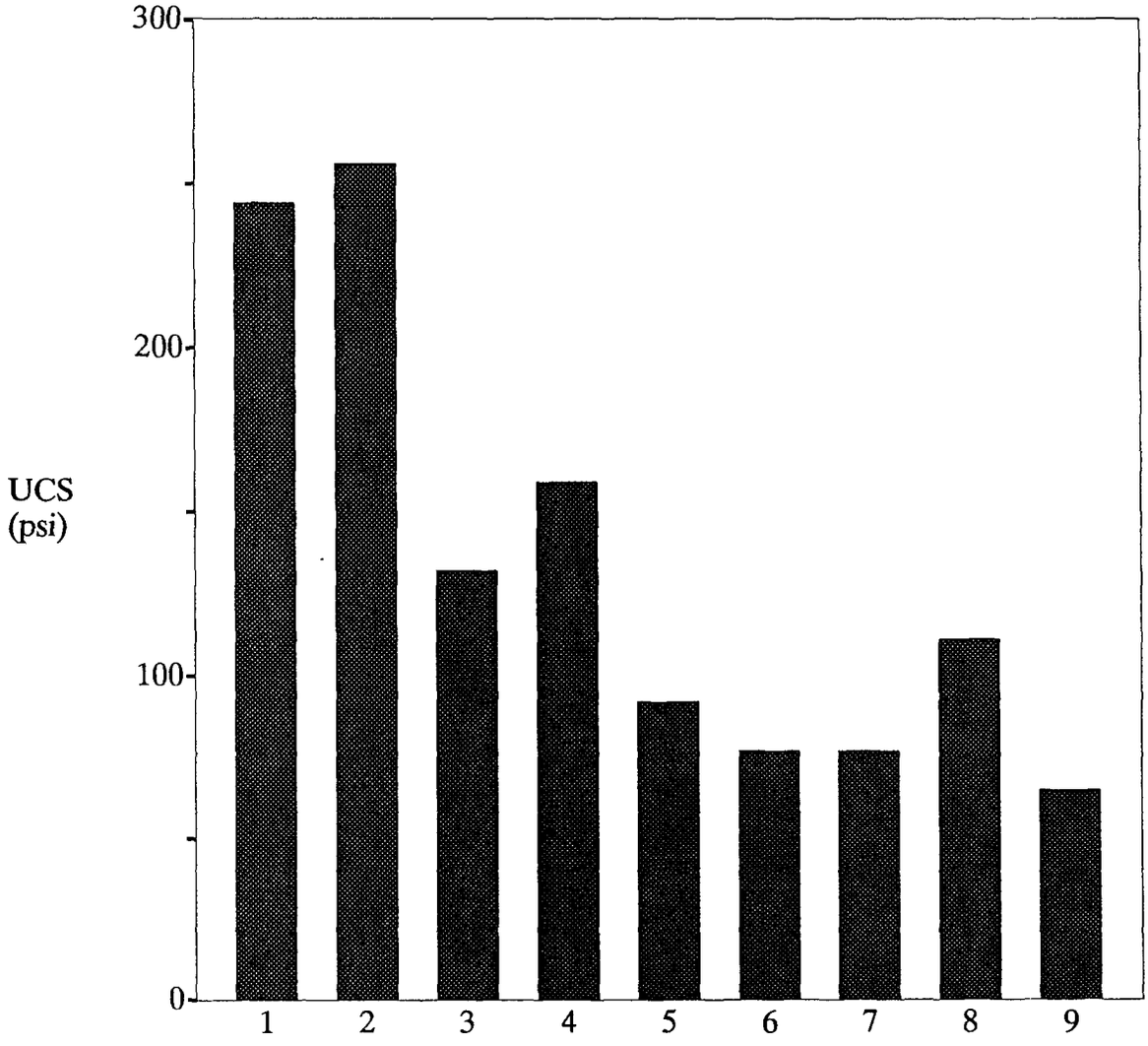


Figure 5-5 Mean UCS From Each Box of Samples of Chemfix-Treated Waste From Area C



Box Number – Boxes are representative of product from beginning to end of treatment of wastes from Area C. Box 1 was taken at start of treatment operations; Box 9 at the end of operations.

values ranged from 334 psi for the second box to 62 psi for the sixth box. The sample from the fifth box broke while soaking, so it had no measurable UCS. The 60-day immersion UCS values ranged from 313 psi in the second box to 74 psi in the fifth box. The 90-day immersion UCS values ranged from 54 psi in the first box to 391 psi in the third box. The mean UCS values for each test period were 177 psi for day 30, 188 psi for day 60, and 204 psi for day 90. Table B-35 and Figure 5-6 show these results. These results indicate no decrease in strength as the result of increasing periods of immersion. This data suggests that the strength found is the result of adhesion between the particles of the matrix.

Like the other test, the variability of the results from samples of product taken at different times during the operation of the treatment process suggests that the treated material emitted from the pug mill was not uniform in composition throughout the operations. Figure 5-7 shows a trend of decreasing immersion strength in the boxes produced throughout the treatment process.

5.4.8 Wet/Dry Weathering Test

Wet/dry weathering tests were performed on molded samples of the posttreatment wastes from Area C according to method TMSWC-12. Results reported from this test shown in Table B-36 are expressed as the cumulative weight loss incurred through 12 wet/dry cycles normalized to a control that is not subjected to the wet/dry cycles. Results of the tests for all the replicates indicate that less than 1 percent of the core weight was lost from the 12 wet/dry cycles. For this test, the control samples lost 0.3 to 1.5 percent of their weight. The results suggest the material successfully withstood the stresses of the wet/dry weathering test with little weight loss, indicating durability in an exposed environment.

5.4.9 Freeze/Thaw Weathering Test

Freeze/thaw weathering tests were performed on molded samples of the posttreatment wastes from Area C according to method TMSWC-11. Results of this test shown in Table B-37 were reported in the same manner as the wet/dry weathering tests. No significant weight loss from test cores was found as a result of 12 freeze/thaw cycles. For this test, controls lost between 0.8 and 1.5 percent of their weight. The results suggest the treated material withstood the stresses of the freeze/thaw weathering test well and will be durable in an exposed environment.

5.4.10 Standard Proctor

The standard proctor test was not performed because the standard method requires an oversized mold if the wastes have high rock content. Such a mold was not planned for and was unavailable for the test.

5.4.11 Slump Test

Slump tests of the posttreatment wastes were determined by ASTM C144. The tests were performed on three representative samples on-site from Areas A, C, E, and F. This test was intended as a real-time indicator of the adequacy of the treatment process to produce a product of consistent quality.

A sample was placed in a dampened slump-test mold on a flat, moist, nonabsorbent surface. The mold was filled in three equal-volume layers. Then, each layer was rodded with 25 strokes of the tamping rod. After the top layer was rodded, excess treated waste was struck off. The mold was immediately removed from the concrete by raising it vertically. The slump was measured by determining the vertical distance between the top of the mold and the original center of the top surface of the specimen. Each test was completed in 2.5 minutes.

Figure 5-6 Mean Immersion Unconfined Compressive Strength for Chemfix-Treated Waste From Area C

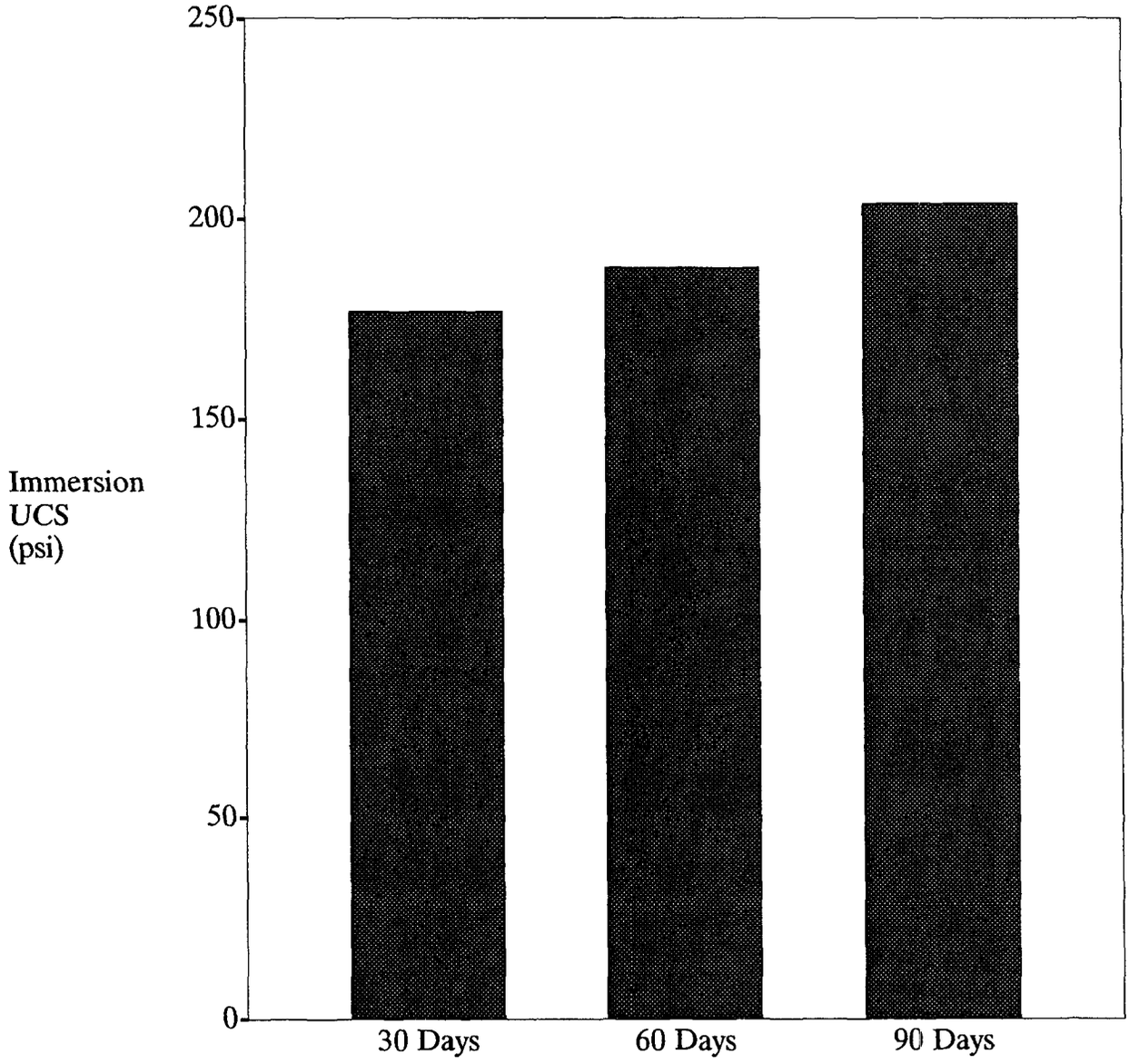
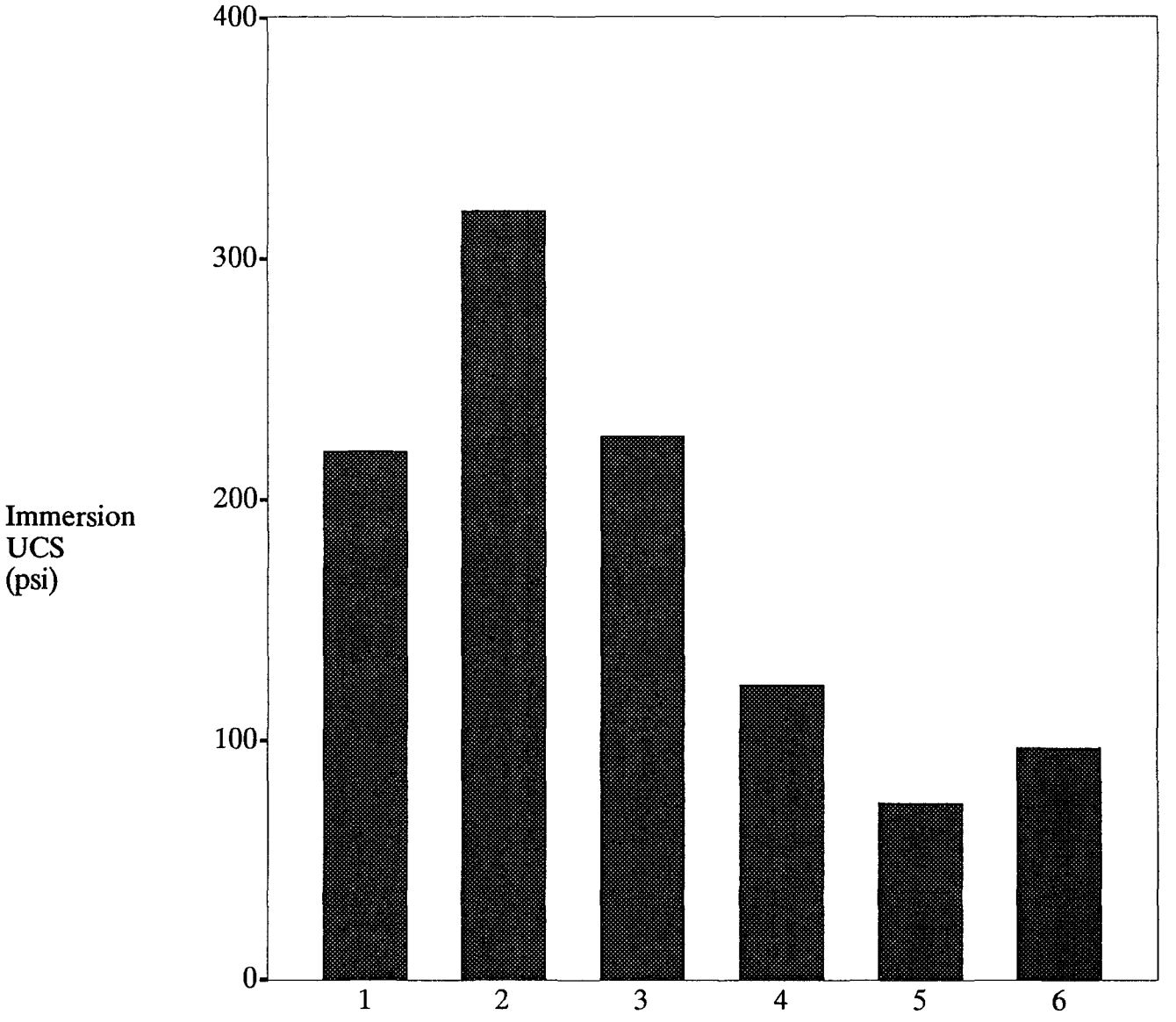


Figure 5-7 Mean Immersion UCS From Each Box of Samples of Chemfix-Treated Waste From Area C



Box Number – Boxes are representative of treatment from beginning to end of treatment of wastes from Area C. Box 1 was taken at the start of treatment; Box 6 at the end of treatment.

Posttreatment waste samples from Areas F and C had average slumps of 2.3 inches and 2.5 inches, respectively. The samples from Area A were too hardened to perform slump tests except for one sample, which had a slump of about 2 inches. The samples from area E did not have any measurable slump.

5.5 POROSITY

The porosity of the treated material is the percent of the volume of material which is air space. It is calculated from the bulk density, percent moisture, and specific gravity using the following equation:

$$\text{Porosity} = 1 - \frac{\text{Bulk Density (1- moisture content)}}{\text{Specific Gravity}}$$

The porosities of the material treated with the Chemfix process are as follows:

Area A - 34 percent

Area C - 36 percent

Area E - 32 percent

Area F - 50 percent

These values for porosity are within the range normally found for solidification/ stabilization products. In another study, using a variety of wastes and solidification/stabilization vendors, an analysis of 69 samples showed a range of porosity of 16 percent to 81 percent with a median of 57 percent (Stegmann and Côte, Draft 1989).

5.6 PETROGRAPHIC EXAMINATION

Samples of the untreated waste and treated waste, after at least 30 days, curing of the treated wastes, were prepared as polished sections and polished thin sections. Petrographic examination was conducted in accordance with ASTM C856, modified as necessary by the petrographer for the nature of these samples. These tests are traditionally done on rocks to study mineralogical associations. They were used here to assess the uniformity of the treated product at a very small scale.

The untreated soil sample contained particles under 1 inch; many of the soil particles were coated with a dusty, oily film. The major constituents were natural materials, including basalt, andesite, and other volcanic rocks. Other constituents were particles of wood, vegetable matter, and manmade materials, such as pieces of metal, glass, ceramic and carbonaceous particles, and bituminous material.

The treated sample consisted of volcanic (soil) filler uniformly distributed in a binder of cement hydration product. Use of portland cement was indicated by the presence of some unhydrated portland cement clinker particles in the binder. The contaminated soil appeared to be uniformly distributed in the cementitious binder. Randomly oriented fine cracks were present in all the cylinders. The cracks may be due to nonuniform shrinkage of the cementitious binder because of poorly controlled curing conditions.

The reader is cautioned that the scale and sample size of this examination are extremely small. No conclusions should be drawn regarding the void space or the mixing of the product as a whole based on this examination.

5.7 PCB DECHLORINATION

Two sets of analyses were conducted to evaluate the effectiveness of the Chemfix process in dechlorinating PCBs. EPA incorporated these tests into the demonstration because Chemfix had preliminary data suggesting such dechlorination. (Chemfix Technologies, Inc., 1987)

The two analyses examined the treated material in two different ways because there was no agreement on the best approach to measure dechlorination. The first test evaluated the concentrations of total PCBs and individual PCB congeners in the waste before and after treatment. Quantifying the concentrations of the individual congeners makes it possible to look at the relative concentrations of the congeners with high chlorine content and low chlorine content. An increase in the concentration of low-chlorine congeners with a corresponding decrease in the concentration of high-chlorine congeners would suggest some dechlorination of the PCB molecule.

Individual PCB homologs (mono through deca) were determined in pretreatment soil samples and treated soil samples aged for 15, 30, 45, and 60 days. Total PCB concentrations are shown in Figure 5-8. These data show considerable variability in total PCB content that was not related to the amount of aging. For example, total PCBs in samples aged 15 and 30 days were approximately 49 and 32 mg/kg, respectively. Samples aged for 45 and 60 days contained 68 and 65 mg/kg, respectively. These differences are attributed to sample heterogeneity created by variation in the amount of Chemfix additives in the waste and the variation in PCB concentrations in raw waste entering the Chemfix processor.

Concentrations of individual PCB homologs (mono through deca) are presented in Table B-38 for each sample type analyzed. This table shows the quantitative distribution of each homolog in each sample type. These data were normalized in relation to the hexa homolog to evaluate the relative distribution of homolog concentrations found in raw waste samples versus those found in treated waste samples. Normalized data are shown in Figure 5-9. These data clearly show the presence of elevated concentrations of di, tri, tetra, and penta homologs in treated samples relative to the raw waste. Marginal decreases were found in hepta and octa homologs, although these differences may not be significant.

In the second set of analyses, the treated product was examined for the presence of any of the by-products of complete dechlorination of PCBs. These by-products, dihydroxy biphenyls, were not found in any samples of the treated wastes. In fact, a library search match between the untreated and treated wastes showed excellent agreement, indicating no chemical change from PCBs to another compound as a result of treatment. Finally, one sample of treated waste was spiked with dihydroxy biphenyls to test the ability of the solvent used in the tests to extract the compound. The spike was recovered at a rate of 92 percent, indicating that the by-products of complete dechlorination would have been found in the treated matrix if they were present.

The results of these two sets of analyses suggest limited dechlorination of the PCB molecules after treatment. It is not known if this partial dechlorination is the result of the treatment process or some other phenomenon such as analytical error, biodegradation, etc. There is no evidence of the products of complete dechlorination, indicating that this limited process of dechlorination does not completely dechlorinate the PCB molecule. No conclusions can be drawn at this time regarding the efficacy of the Chemfix process in dechlorinating PCB.

5.8 AIR MONITORING

The concentration of PCBs in ambient air in close proximity to and downwind of the Chemfix equipment was measured with a high-volume air sampling device. This sampler consisted of a glass fiber filter for particulate capture and a polyurethane foam (PUF) sorbent cartridge for retention of vapor-phase PCBs. PCBs were determined for the combined extract of

Figure 5-8 Total PCB Concentrations in Treated and Untreated Soils From Area A

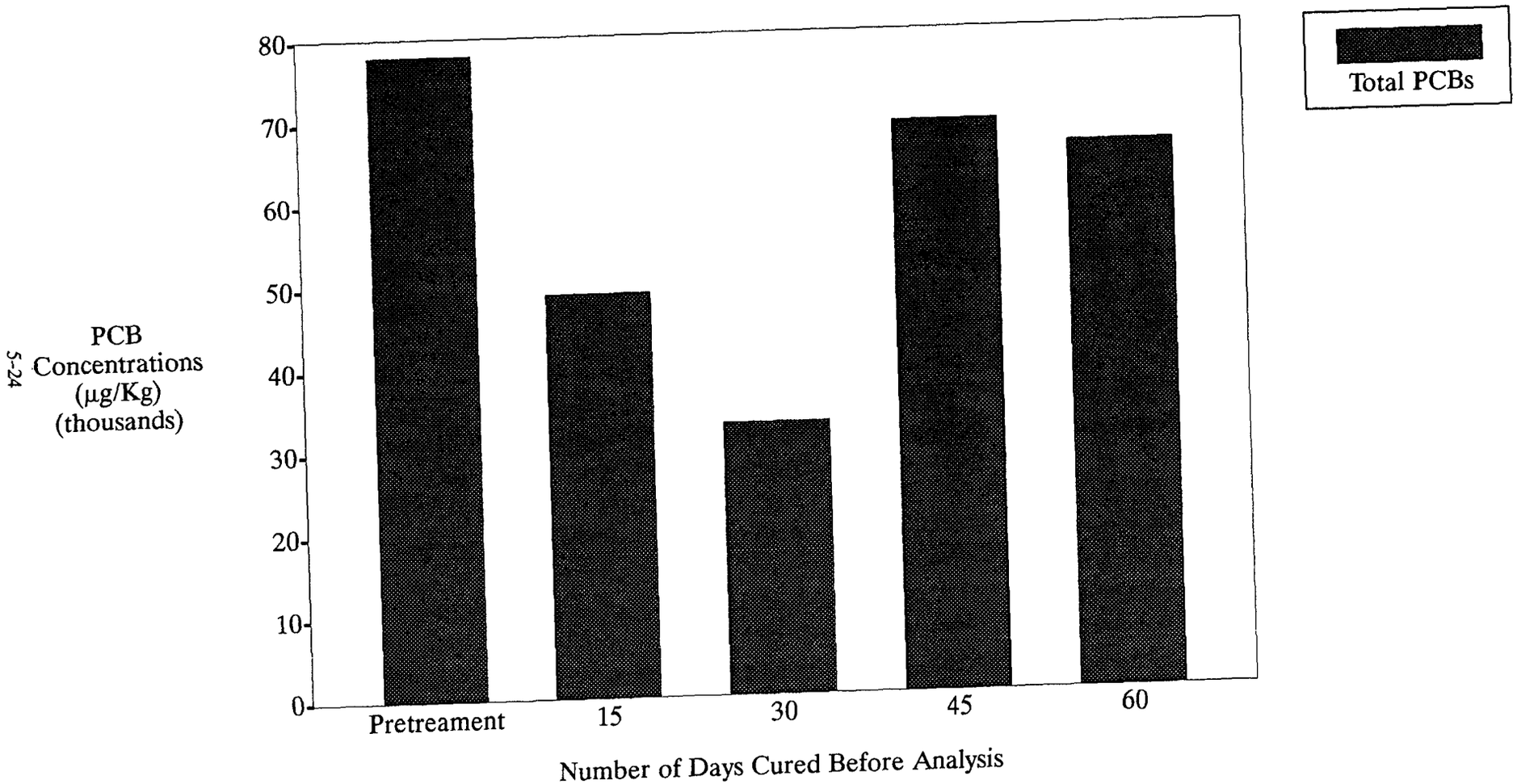
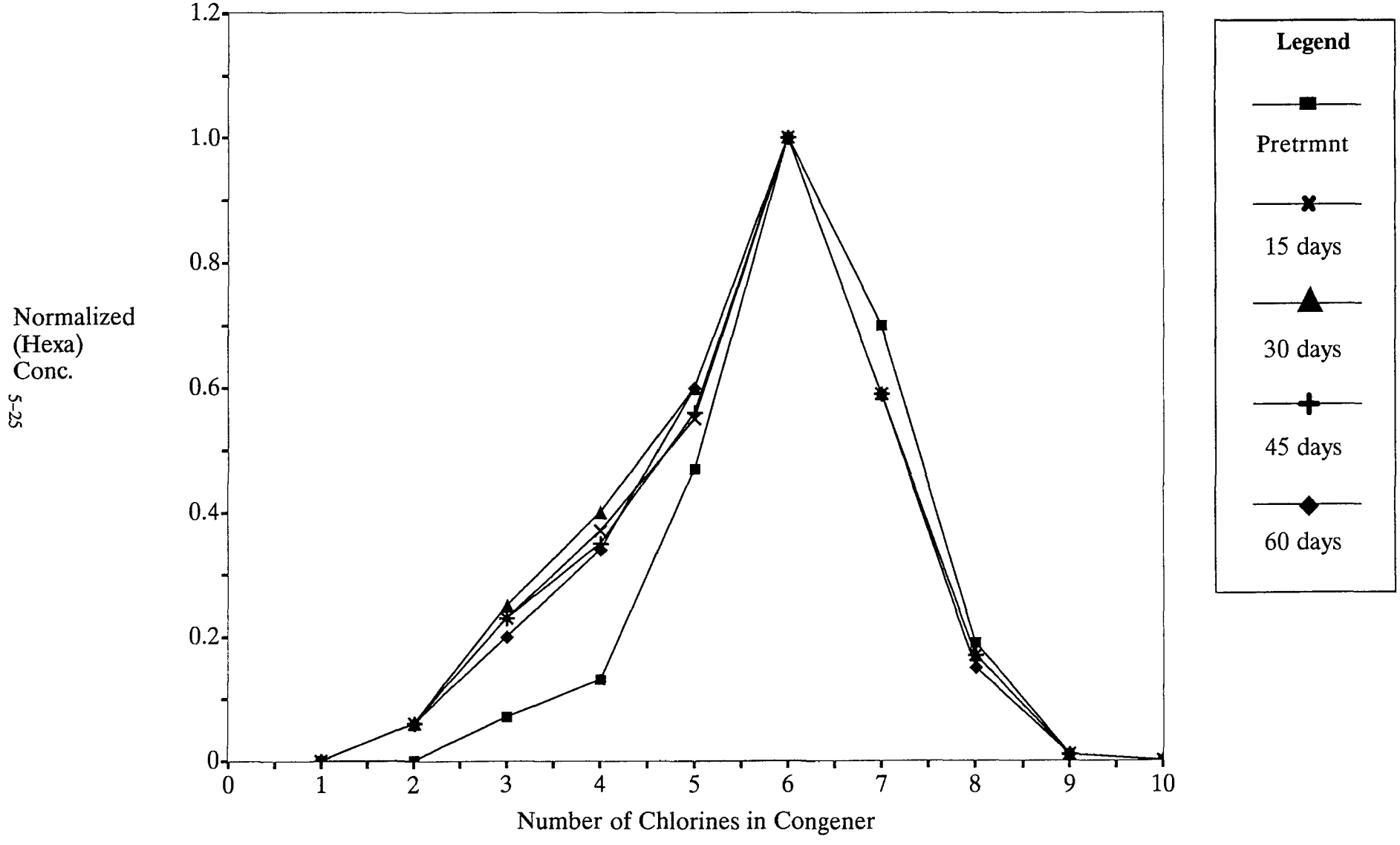


Figure 5-9 Normalized PCB Concentrations for the Treated and Untreated Soils From Area A



filter and PUF samples, providing an indication of total PCB content in sampled air. Table B-39 presents results from the air monitoring activities.

PCBs were not found in either field or trip blank samples, indicating that there was no PCB contamination associated with the assembly and disassembly of the sampling apparatus, the clean filters, or the PUF cartridges. The ambient blank sample was collected at the center of the PESC worksite 1 day before demonstration activities began. This sample contained mono through hexa-PCB congeners at concentrations ranging from 0.7 to 12 ng/m^4. These concentrations are characteristic of an urban environment in the United States. PCB analysis of remaining samples indicated PCB concentrations were not different from the ambient control sample. In addition, there were no apparent differences in PCB concentrations between upwind and downwind samples associated with Areas A, E, and F.

These data suggest that no volatilization of PCBs occurs during the treatment process. However, the weather conditions during the demonstration were wet and cool, conditions that would tend to limit volatilization.

5.9 LONG-TERM TESTS

Samples of treated material from the PESC site will be analyzed using the TCLP, ANS 16.1, UCS, and acid neutralization capacity (ANC) tests for five years. The results of the first round of tests, six months after the demonstration, show results for the ANS 16.1, UCS, and ANC which are very similar to those reported above. The leachability index for lead from the ANS 16.1 at 6 months is 14.6, the mean UCS is 166 psi, and the mean ANC is 5.0 meq/g.

The results of the TCLP after 6 months shows higher concentrations of metals in the extracts than reported above. The mean concentration of lead in the TCLP extracts from Area C is 12 mg/L and all of the samples would have failed the demonstration-specific soil standard of 5.0 mg/L. The reader should note that tests run after a period of aging in the lab may not be comparable to earlier analyses because the specimens may have changed chemically.

The results for the long term monitoring to be conducted in the future will be available from EPA after they are completed.

5.10 MATERIALS BALANCE

This section describes materials balance, the dilution factor, and the volume expansion ratio. These analyses provide information on the dilution of wastes that occurred as a result of treatment. When comparing the concentrations of contaminants in the TCLP extracts or total contaminant concentrations in the wastes before and after treatment, it is important to consider the dilution that occurred as a result of the addition of reagents as part of the process. In addition, this analysis provides information on the quantity of material that will require land disposal capacity if this process is used. The volume expansion ratio can be used to estimate final disposal capacity needed for a known quantity of raw waste.

5.10.1 Materials Balance

Table 5-5 presents materials balance information for each of the four test runs performed by Chemfix during the demonstration. The data in this table are based upon information collected during the demonstration and information obtained from laboratory analysis.

Approximately 4 to 7 tons of wet soil material (as measured at the Chemfix weight feeder) were treated for each test run. Dry reagent was added for each test run in amounts that varied from 12 to 21 percent of the wet soil material by weight, with an average value of 17

Table 5-5

Summary of Chemfix Operating Conditions

	Area A	Area C	Area E	Area F	Average
Total soil (screened) kg[a]	4,218	5,153	5,779	5,434	5,146
Total dry reagent, kg[b] (Chemset I-20)	526	780	1,070	1,143	880
Total liquid reagent, kg[c] (water included) (Chemset C220)	886	1,082	1,017	1,027	1,002
Total weight, kg	5,630	7,014	7,865	7,604	7,029
Slurry bulk density, g/cm^3	1.9	2.0	1.9	1.6	1.7
Total volume, m^3	2.9	4.4	4.1	4.5	4.7
Dry reagent-to-soil ratio	0.12	0.15	0.19	0.21	0.17
Liquid reagent and water-to-soil ratio	0.21	0.21	0.18	0.19	0.20
Soil-to-total-feed ratio	0.75	0.73	0.73	0.71	0.73
Operating time, seconds[f]	1200	780	1140	960	1020
Soil feed, kg/sec	4.5	6.6	5.1	5.7	5.0
Dry reagent, kg/sec	.44	1.0	.94	1.2	.9
Liquid reagent, kg/sec	.74	1.4	.89	1.1	1.0
Total feed addition, kg/sec	4.7	9.0	6.9	7.9	6.9

Notes:

a The weight of soil used was obtained from Chemfix weight feeder totalizer.
b The weight of dry reagent added was obtained from Chemfix reagent totalizer.
c The weight of diluted liquid reagent added was based on reading from Chemfix flow meter (gallon) and 11.04 lb/gallon.
d Slurry bulk density was obtained from Radian's laboratory analysis.
e Total volume was calculated based on total weight and bulk density.
f The operating time was checked with a stopwatch.

percent. However, the amount of diluted liquid reagent added was relatively consistent for each test run (an average 20 percent of wet soil weight). Each test run produced approximately 4 to 6 cubic yards of treated material.

5.10.2 Dilution Factor

Reductions in leachable lead or copper concentrations in the treated wastes may result from diluting the raw wastes with binders used in the treatment process. Therefore, a dilution factor was calculated for each test run, using the following equation:

$$DF = \frac{W_r + W_w}{W_r}$$

where

DF	=	dilution factor
W_r	=	mass of raw waste
W_w	=	mass of Chemfix reagents and water

For example, the mass of raw waste treated for Area C was 5,153 kilograms. The mass of the Chemfix reagents for the Area C test run was 1,862 kilograms. The calculation of the dilution factor follows:

$$\text{Dilution factor} = \frac{5153 + 1862}{5153} = 1.4$$

The dilution factor determined for each area waste is shown below:

Area	Dilution Factor
Area A	1.3
Area C	1.4
Area E	1.4
Area F	1.4

5.10.3 Volume Expansion Ratio

The volume expansion ratio (VER) between treated waste and screened raw waste was calculated for each test run using the following equation:

$$VER = \frac{(W_s + W_w)B_s}{B_t \bullet W_s}$$

where

VER	=	volume expansion ratio
W_s	=	mass of screened raw waste
W_w	=	mass of Chemfix reagents and water
B_s	=	bulk density of screened raw waste (1.7 to 2.0 g/cm^3)
B_t	=	bulk density of treated wastes (1.8 to 2.0 g/cm^3)

The bulk density values for the excavated, screened raw waste used in this calculation are the average of the measurements made in the field using unpacked material and those made in the laboratory with packed material. The difficulty in obtaining in-situ bulk density measurements affects the validity of these calculations. The total volume expansion of the wastes from before excavation until after treatment will not be calculated because of the lack of information on in-situ bulk density. This total VER would provide the most accurate measure of the actual volume needed to dispose of the wastes.

For example, the factors for Area C are as follows:

W_s = 11,360 pounds
W_w = 4,105 pounds
B_s = 2.0 g/cm^3 (123 lb/ft^3)
B_t = 2.0 g/cm^3 (123 lb/ft^3)

$$\frac{(11{,}360 + 4{,}105)\ \text{lbs}}{11{,}360\ \text{lbs}} \times \frac{123\ \text{lb/ft}^3}{123\ \text{lb/ft}^3} = 1.4$$

The VER determined for each area waste is shown below:

Area	Volume Expansion Ratio
Area A	1.2
Area C	1.4
Area E	1.3
Area F	1.5

The contaminated soils from the PESC site increased in volume between 20 percent and 50 percent as a result of treatment, based on this calculation.

The VER may allow prospective users of the Chemfix technology to estimate the volume of treated waste that will need to be disposed of and transported or stored if they know how much raw waste is present at a site. It should be noted, however, that the VER is a site-specific value, because it requires an estimate of the in-situ bulk density of the raw waste.

5.11 QUALITY ASSURANCE/QUALITY CONTROL PLAN AND RESULTS

5.11.1 Quality Assurance/Quality Control Plan

The Chemfix demonstration plan included a quality assurance project plan (QAPjP) that detailed QA/QC procedures for the demonstration sampling and analysis activities. These QA/QC procedures included the following:

- QC check samples -- Standard samples of known analyte concentrations were checked.
- Laboratory blank samples -- The laboratory analyzed calibration, extraction, and method blanks. Calibration blanks consisted of deionized water and were not taken through any sample preparation steps. Extraction blanks were deionized water that had been taken through the organic extraction procedures only. Method blanks consisted of deionized (or organic-free) water and were taken through all sample preparation steps, including addition of reagents and digestion/extraction procedures.
- Calibration check compounds -- Standards were used for ongoing calibration verification.
- Matrix spike samples -- A small subset of the samples was spiked with known concentrations of either reference materials or surrogate standards and taken through the sample preparation process. Spiked samples allowed the laboratory to assess the efficiency of extraction processes, the accuracy of the analyses, and possible matrix effects.

- Matrix spike duplicate samples -- Matrix spikes were prepared in duplicate and analyzed. These samples provided a measure of sampling and analytical variability in a given matrix.

- Replicate samples -- These samples were prepared in duplicate at a 10 percent frequency. The replicate sample analyses provided a measure of sampling and analytical variability.

- Duplicate analyses -- Sample extracts, digestates, or leachates were analyzed in duplicate at a 10 percent frequency. Duplicate sample analyses provided a measure of analytical variability.

EPA performed a laboratory audit to ensure that all QA/QC procedures were being followed. The laboratory audit found the analysis activities satisfactory.

5.11.2 QA/QC Results

Many different types of analyses (engineering and geotechnical, leaching tests, and chemical and physical tests) were performed on the samples collected for this project. The two major sample matrices for this project were pretreatment (or untreated) soils and treated (solidified) soils. An additional three sample submatrices were generated through leaching tests performed on the two major sample matrices. These additional sample types were extracts from the following leaching procedures:

- Toxicity characteristic leaching procedure (TCLP)

- American Nuclear Society 16.1 Test (ANS 16.1)

- Modified EPA Method 1310 (MEP)

The major analyses performed for which quality control (QC) results are available were metals (by ICPES, cold vapor atomic absorption spectroscopy, and graphite furnace atomic absorption spectroscopy methods), PCBs, VOCs, SVOCs, dioxins and furans, oil and grease, TOC, filterable residue (also known as total dissolved solids--TDS), and PCB dechlorination by GC/MS.

QC tests associated with the methods used for this project included multipoint calibrations (mixed standard calibrations for metals by the ICPES system); measure of precision through the use of duplicate samples and duplicate analyses; matrix spike and surrogate spike sample; and calibration, analytical, preparation, and leaching (TCLP, BET, ANS 16.1, or MEP) blanks.

Pretreatment samples analyzed for the Chemfix project consist of three submatrices: soil samples, MEP leachates of soil samples, and TCLP leachates of soil samples. Problems associated with these matrices include the following:

- High variability and low recovery of metals matrix spike samples in pretreatment soil samples due to the high levels of metals contained in the sample

- Low recoveries of one matrix spike compound and one surrogate spike compound in pretreatment soil samples analyzed by Method 8270

- Low surrogate spike recoveries for some soil samples analyzed by Method 8280

- High variability of field duplicate samples of TCLP leachates analyzed for metals

- Low matrix spike recovery of selenium in TCLP leachates.

Posttreatment samples for the Chemfix project consisted of four submatrices: posttreatment solid samples, TCLP leachates, MEP leachates, and ANS 16.1 leachates of posttreatment solid samples. The following concerns are associated with the posttreatment solid samples:

- High metal concentrations in the posttreatment field samples may have caused low recovery and high variability in matrix spike results.
- Matrix spike recoveries suggest that field results for arsenic, selenium, and thallium in posttreatment samples may be underestimated.
- Matrix spike recoveries for Method 680 were low, which may mean that results for posttreatment field samples are slightly underestimated.
- Low matrix spike recoveries were reported for selenium, lead, and mercury in TCLP leachates analyzed by ICPES and A4.
- Low matrix spike recoveries were reported for selenium in MEP leachates.
- Copper and sodium were detected in the ANS preparation blank.

Overall, the QC results were excellent. Approximately, 89 percent of the duplicate tests, 86 percent of the matrix spike tests, 89 percent of the surrogate spike tests, and 97 percent of the blank tests yielded results within the acceptable criteria for both pre- and posttreatment samples.

5.12 SUMMARY OF RESULTS

Table 5-6 summarizes the objectives of the demonstration, the test methods to meet those objectives, and the results of the analyses.

Table 5-6

Summary of Demonstration Objectives, Test Methods, and Results

Objective	Approach/Method	Results
Primary		
• Determine whether wastes treated by the technology meet or exceed RCRA land ban standards for lead.	Compare lead concentrations in TCLP leachates of treated wastes to chosen demonstration standard of 5.0 mg/L for soil and RCRA listed wastes (electroplating sludges) standard of .51 mg/L.	See Tables B-1 to B-5. 70% of samples met demonstration standard. 65% met the RCRA land ban standard.
Secondary		
• Determine the effectiveness of the process in reducing lead and copper concentrations in leachates obtained using the TCLP on raw and treated wastes.	Compare TCLP lead and copper concentrations in TCLP leachates from treated wastes with those from raw wastes. These percent reductions were compared to interim standards for Superfund soil and debris for RCRA land ban.	See Table 3-4. Percent reductions of mean TCLP lead and copper concentrations from untreated to treated wastes were 94.5 to 99.9 (for lead) and 95.5 to 99.4 (for copper).
• Determine the effectiveness of the process in reducing PCB concentrations in TCLP leachates to 1 ppm or less.*	Compare PCB concentrations in TCLP leachates from treated wastes with those from raw wastes.	See Table B-1. PCBs were not found in the leachates of raw wastes. Therefore, no conclusions could be drawn.
• Determine whether the treatment process dechlorinates PCBs over time.	Compare PCB concentrations in treated wastes at 15, 30, 45, and 60 days after treatment using EPA Method 680. Identify the presence of reaction products, using a new analytical approach, to determine whether dechlorination, rather than adsorption, has occurred during the curing process.	See Figure 4-10. Data suggest the partial dechlorination of PCBs to less chlorinated congeners. No evidence of total dechlorination of PCBs to another compound was found. Partial dechlorination may not be due to stabilization process.
• Determine baseline physical properties of the raw wastes to establish a basis for evaluating process performance.	Analyze raw wastes for particle size, percent moisture, standard proctor value, porosity, bulk density, and specific gravity.	See Tables B-29 to B-34.

* This objective was dropped because PCB concentrations in the TCLP leachates of raw and treated wastes (preliminary sampling) did not exceed detection levels.

Table 5-6

Summary of Demonstration Objectives, Test Methods, and Results (Continued)

Objectives	Approach/Method	Results
Secondary		
• Determine the chemical properties of the raw wastes to establish a basis for evaluating process performance.	Analyze raw wastes for acid neutralization capacity, TOC, pH, Eh, oil and grease, electrical conductivity, total PCBs, total lead, total copper, lead compounds, humic acid, and dioxin.	See Tables B-29 to B-34.
• Determine physical properties of treated wastes to indicate their long-term permanence and placability.	Subject treated wastes to permeability, wet/dry, freeze/thaw, water content, bulk density, specific gravity, and porosity tests.	See Table 3-5 and B-34 to B-37. Results show that UCS is relatively constant after 14 days. The products showed resistance to freeze/thaw and wet/dry weathering tests.
• Determine chemical properties of treated wastes.	Analyze treated wastes for lead, copper, PCBs, TOC, pH, Eh, oil and grease, electrical conductivity, and acid neutralization potential.	See Tables B-29 to B-34. The acid neutralization capacity, electrical conductivity, and pH of the wastes increased dramatically with treatment. Eh was lower after treatment.
• Determine leaching properties of treated wastes to indicate their long-term chemical stability.	Subject treated wastes to a number of different leaching tests.	See Tables B-6 to B-22. Mean lead concentrations in the MEP extracts from the posttreatment samples generally exceeded the RCRA regulatory level of 5 mg/L for the first extraction. The mean concentrations from the last two extractions showed a trend upward. The ANS 16.1 results suggest that diffusion is the controlling mechanism of contaminants from the matrix. The results met the NRC standard for the leachability index. However, the calculated fluxes from this test should be used in a ground water model for site specific applications.
• Determine the homogeneity of mixing and structural characteristics of the treated wastes.	Conduct x-ray diffraction, petrographic, and scanning electron microscopy examinations of the treated and raw wastes. These studies are on a scale which is too small to allow conclusions on the product as a whole.	These studies are on a scale which is too small to allow conclusions regarding the product as a whole.

Table 5-6

Summary of Demonstration Objectives, Test Methods, and Results (Continued)

Objectives	Approach/Method	Results
Secondary		
• Determine whether significant PCB concentrations are released to the air by the treatment process.	Monitor the PCB air concentrations in the immediate vicinity of the Chemfix processing equipment during the treatment process.	See Table B-39. No significant increase in PCB concentration was found during the treatment process.
• Determine the dilution effects on any reductions of lead and copper concentrations in leachates obtained from treated wastes.	Measure the mass of wastes, water, and treatment reagents used in each test run and use these measurements to calculate dilution factors.	Dilution factors for the treated wastes varied between 1.33 and 1.4.
• Determine the effects of aging on the leachability, acid neutralization capacity, and strength of the treated wastes.	Conduct x-ray diffraction, petrographic, and scanning electron microscopy examinations of the treated and raw wastes.	No major changes after 6 months.
• Determine total cost and major cost factors associated with the process.	Evaluate the costs of all materials, equipment, and services needed to complete the demonstration.	See Chapter 5.0. $41 to $80 per ton of waste material treated, plus $20,000 in site preparation, plus cost to mobilize Chemfix equipment, plus cost of placement or land disposal.

Notes:

RCRA, Resource Conservation and Recovery Act; TCLP, toxicity characteristic leaching procedure; PCB, polychlorinated biphenyl; EPA, Environmental Protection Agency; TOC, total organic carbon; UCS, unconfined compressive strength; MEP, multiple extraction procedure; ANS, American Nuclear Society; NRC, Nuclear Regulatory Commission.

6.0 COST ANALYSIS

6.1 PURPOSE

One objective of the Superfund Innovative Technology Evaluation (SITE) demonstration program is to establish reliable cost information for use in analysis and decision making regarding future site cleanups. Costs of treatment for this technology come from the Chemfix process itself and the operations necessary before and after application of the technology. Many of the latter costs would be incurred regardless of the solidification/stabilization process used and are not unique to the Chemfix process.

It is not possible to directly analyze the process costs by comparing them with competitive prices because the Chemfix process uses proprietary and patented equipment and reagents. Instead, this section analyzes the cost model provided by Chemfix Technologies, Inc. based on EPA experience, information from the SITE demonstration, and general cost information on solidification/stabilization processes. Although the costs associated with the SITE demonstration are considered here, it is understood that many of the costs of the demonstration may not be representative of any actual site operation.

Uncertainty and variability in the cost of using the Chemfix technology come from two sources: (1) site-specific and waste-specific differences in the operations needed before the application of the technology, and (2) differences in the rate at which the waste can be processed.

6.2 THE CHEMFIX COST MODEL

Chemfix Technologies, Inc., provided a cost model for estimating the cost of operating the treatment process. The model includes a range of expected costs per ton of material treated for reagents, labor, miscellaneous operating expenses, and capital equipment, as well as an estimate of mobilization and demobilization costs. Table 6-1 summarizes this cost model.

Because the model provides the range of costs in terms of cost per ton processed, the accuracy of the estimates will depend on the rate at which material can be processed. According to Chemfix, its standard processing unit can treat liquid wastes at a rate of 200 to 300 gallons per minute. The Chemfix estimate for solid wastes is 200 to 500 cubic yards per day. These rates were used to calculate the cost ranges for the treatment. Lower processing rates will result in higher costs per ton for equipment and labor, while higher rates of processing will lower the costs per ton.

During the SITE demonstration, material was processed at a rate of 15 tons per hour including both processing and downtime. As described in Appendix A, the processing of the material during the demonstration was done in relatively small test runs that were interrupted several times due to processing problems that were not attributable to the Chemfix process. In general, the rate of processing for a demonstration is likely to be less than that found on a full-scale operation. A conservative estimate of processing rate is 20 tons per hour or 160 tons per day, assuming 8 hours of processing per day. Therefore, the range of processing rates provided by the Chemfix cost model appears somewhat high.

6.2.1 Processing Costs

The costs of reagent, labor, capital equipment, and miscellaneous expenses are considered processing costs that depend on the quantity of material treated. The following sections compare the ranges of costs provided for these categories by the Chemfix cost model to cost information on similar items.

Table 6-1

Chemfix Cost Model

Processing Costs

Category	Rate	EPA Commentary
Labor	$5 to $15 per ton. Will vary with speed of processing and quantity to be processed.	Realistic*
Reagent	$25 to $30 per ton. Will vary with moisture content of the waste (moisture or lack of moisture in the soil).	Realistic
Miscellaneous operating expenses with maintenance (includes health and safety)	$2 to $4 per ton.	Realistic
Capital equipment	$3 to $5 per ton. Will vary with processing rate.	Slightly low*

Mobilization and Demobilization Costs

Category	Rate	EPA Commentary
Equipment transfer expense	$2.50 per loaded mile (from point of origin to site and return) x number of trucks used	Realistic
Labor costs per day with expenses	$380 per day x number of people employed x number of days	Realistic
Miscellaneous site expenses	$100 per day x number of days	Very low
Travel expenses for crew	$500 (approximate x number of people)	Realistic

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* The costs of labor and equipment shown here are realistic for the Chemfix process only. The labor and equipment needed to get the waste to the unit (excavation and materials handling) and process it will approximately double the costs shown here.

6.2.1.1 Reagent Cost

The cost impact of reagent input to the Chemfix process depends on the required concentrations. The exact proportions of the dry (CHEMSET I-20) and liquid (CHEMSET C-220) reagents in the Chemfix process are proprietary information. The company quotes a cost range of $25 to $35 per ton of material handled. This range appears to be broadly consistent with costs associated with alternative reagents and reagent concentrations that can be used for this type of mixing plant stabilization/solidification process. For example, treatment with portland cement (30 percent by weight) and sodium silicate (2 percent by weight) (reagents similar to those used in the Chemfix process) yields a cost of $21 per ton of waste treated. Other materials that can be used in mixing plant stabilization/solidification processes also yield reagent costs per ton in the range quoted by Chemfix. Alternative processes not using cement, such as pozzolanic processes (for example, those based on reaction of fly ash with lime), can require similar costs for reagents. Fly ash (Type F) (80 percent by weight of reagent) and lime (20 percent by weight of reagent) can be used at a cost of $34 per ton of waste.

6.2.1.2 Labor Cost

As mentioned above, the rate at which waste material is processed will affect the labor cost significantly. Chemfix estimates that the processing equipment alone will require a crew of four to five workers. If this crew includes four technicians and one senior project engineer working 10-hour shifts, the labor costs per day are as follows:

4 Trained Technicians	4 x $366 = $1,464
1 Engineer	1 X $468 = $ 468
Total Daily Cost of Crew	$1,932

If one assumes expenses of $100 per day per worker, the total cost of the labor to run the Chemfix process equipment for each day is $2,432. The labor cost for the Chemfix process itself will therefore range from $5 to $15 per ton of material processed, depending on the processing rate. This figure is a typical national average; regional variation is significant, with higher rates expected in New England, New York/New Jersey, and California. This cost range compares with the labor costs provided by the Chemfix cost model of up to $15 per ton, including expenses.

It should be noted that this labor cost is for the operation of the Chemfix equipment only. In addition to this labor, workers are needed to excavate the waste material, transport it to the treatment unit, take samples, monitor health and safety conditions, and generally maintain the site. The costs for this labor are discussed in Section 6.3, Other Operating Costs.

6.2.1.3 Capital Equipment Cost

Since Chemfix does not sell the patented capital equipment used in the process, it must be rented from the company at a rate of $5,000 per week. This rental rate includes the cost of the homogenizer, feed hopper, reagent units, mixer, and other pumps and equipment. This cost may be compared with the cost to rent a common concrete mixer for a week, $3,000 to $4,800. Based on this comparison, the Chemfix rental rates appear to be within a reasonable range for similar, nonpatented equipment.

Assuming a weekly rate of $6,000 and a production rate of 160 to 500 cubic yards per day, the capital equipment cost is $2.50 to $7.50 per ton of wastes processed. The Chemfix cost model gives a range of $3 to $5 per ton.

6.2.1.4 Miscellaneous Operating Expenses With Maintenance

The Chemfix model estimates miscellaneous operating costs to total $2 to $4 per ton. These costs include utilities (fuel, water) and supplies and consumables other than the reagents (containers, liners, decontamination and waste storage materials, etc.).

6.2.2 Mobilization and Demobilization Costs

Chemfix's cost model also provides an estimate of the costs to mobilize and demobilize for a hazardous waste site cleanup. Mobilization costs include equipment transfer expense, labor costs per day with expenses, miscellaneous site expenses, and travel expenses for crew. Chemfix has indicated that overall demobilization costs could range from 60 percent to 100 percent of the mobilization costs. Mobilization and demobilization costs are fixed costs. They will decrease as a unit cost per ton of material treated as the volume of material treated increases.

6.2.2.1 Equipment Transfer Expense

Chemfix's estimate of $2.50 per loaded mile per truck of the required two-way trip between the equipment point of origin and the site appears to be realistic considering the cost of labor and gas. Only the Chemfix process equipment is likely to be transported over long distances. However, transport costs of many of the other pieces of equipment required for mobilization, processing, and demobilization can add significantly to costs even if they are supplied locally. Depending on specific conditions, transport could add hundreds of dollars to costs.

6.2.2.2 Labor Costs Per Day With Expenses

Labor costs for the pre- and postprocessing phases in the Chemfix model appear to be roughly correct, although the average for the type of personnel in the crew is likely to be somewhat lower, as specified above in the assessment of processing phase labor costs. Again, per diem expenses will depend on the nature of the project and whether local crews are used.

6.2.2.3 Miscellaneous Site Expenses

In the SITE demonstration of the Chemfix process, mobilization and demobilization of the equipment at the test site each took approximately 7 days. The Chemfix model gives an estimate of $100 per day for miscellaneous site expenses for mobilization and demobilization, or about $700 for mobilization and $700 for demobilization, based on these estimated durations.

Given the nature of the costs incurred in site preparation, startup, and demobilization for the SITE demonstration, this component of the costs in the Chemfix model appears to be low. Many of the site preparation, startup, and demobilization costs incurred for the demonstration of the Chemfix process are indicative of costs likely to be incurred in actual process application. For the demonstration, site preparation costs related to installation of power hookups totaled about $2,050, for example. Expenses totaled over $5,500 for other equipment and material used in the startup phase, such as a crane to lift the equipment into place, an arc welder, a trash pump, a four-way cable pack, an air wrench, protective clothing for the crew, and miscellaneous items. Costs for the 1-week demobilization of the demonstration, including garbage pickup and earth-moving equipment costs, plant dismantling, and protective clothing for the crew totaled over $6,000. None of these costs include equipment costs during the period of actual waste processing. The costs of mobilizing and demobilizing the Chemfix equipment itself for the SITE demonstration exceeded $12,000. Miscellaneous expenses for mobilization and demobilization are likely to substantially exceed the amount indicated by the Chemfix model.

6.2.2.4 Travel Expenses for Crew

Chemfix estimates travel expenses to be $500 per person on average. The required distance for personnel travel will be the determining factor, making actual costs somewhat lower for shorter trips and somewhat higher for longer trips. For waste processing projects of a long-term nature, it is possible that local crews could be hired to save on travel (particularly home leave).

6.2.3 Summary Assessment of the Determinants of the Chemfix Model Costs

The Chemfix model appears to be fairly realistic for most of the components of processing costs, including reagents, labor, miscellaneous operating expenses with maintenance, and capital costs of the Chemfix process equipment. The rate of processing is a determinant of both process equipment costs and labor costs per ton, and the maximum feasible rate is a function of the qualities of the waste material handled. Processing rates for contaminated solids are significantly lower than for liquids and low-solid-content slurries. Geographical variation in labor rates and the exact composition of the crew can also affect labor costs. Reagent costs per ton of waste depend on optimal reagent concentrations and the costs of these materials.

Some components of mobilization and demobilization costs in the Chemfix model appear realistic, including equipment transfer expenses (although local transport of ancillary equipment must not be overlooked), labor costs, and travel expenses for the crew. However, the Chemfix model appears to substantially underestimate the ancillary equipment rental costs during mobilization and demobilization. Key variables determining mobilization and demobilization costs are the Chemfix equipment transfer distance, duration of these phases of the work, and ancillary equipment rental rates and labor rates.

6.3 OTHER OPERATING COSTS

Chemfix's cost model provides an estimate of many of the costs associated with the direct mobilization, use, and demobilization of the Chemfix process. In addition to these costs, there will usually be substantial costs associated with getting the Superfund site ready for a cleanup action, excavating the wastes, and clearing the site after the treatment process. In other words, the Chemfix cost estimates are valid for most of the costs of actually running the process but they do not account for substantial costs associated with the following activities:

- Setting up the decontamination facilities
- Establishing phone lines to the site
- Preparing gravel roads and parking areas
- Excavating the wastes
- Back-filling the excavation, if necessary
- Taking samples
- Monitoring health and safety conditions

The costs for these activities will vary significantly, depending on site conditions. In addition to these common items, some sites will require additional materials handling and pretreatment operations that will also add costs. This section will describe some of the additional costs that may be expected in preparing a site for an application of the Chemfix technology. It is assumed that only one Chemfix unit is used and the cost of labor and materials is calculated to support only one unit.

6.3.1 Site Preparation Costs

The site preparation costs for the SITE demonstration were approximately $5,000. This cost excludes the cost of travel to the site for work crews. The most expensive components of

these costs were plates for the decontamination pit, transport of the command trailer, rental of an electric generator and telephone hookups. These costs do not include transportation costs for the work crews.

6.3.2 Startup Costs

The startup costs for the SITE demonstration were approximately $7,000. These costs are in addition to those included in the Chemfix cost model. The most expensive components of these costs were rental of a backhoe to excavate the decontamination pit and rental of a front-end loader.

6.3.3 Capital Equipment Costs

Additional capital equipment costs for the SITE demonstration included such things as a generator, protective clothing for the crew, a backhoe for excavation of the wastes, and pressure washers for decontamination of equipment. These costs, which are in addition to the costs included in the cost model, totaled approximately $6,000 per week, doubling the costs of the Chemfix process equipment. Assuming the process can treat 160 to 500 cubic yards per day, these miscellaneous capital equipment costs will add approximately $2.50 to $7.50 per ton of wastes treated to the cost of the process, for a total cost of $5 to $15 per ton of waste treated.

6.3.4 Labor Costs

In addition to the labor costs identified in the cost model to run the Chemfix equipment, a work crew will be needed to excavate soil and deliver it to the Chemfix equipment, sample the soil and the treated wastes, monitor the health and safety conditions, and direct the overall project. The estimated cost for the labor of these workers follows:

2 Technicians (sampling technician and health and safety officer)	$ 366 x 2
2 Laborers (backhoe operator and 1 general crew)	315 x 2
1 Resident Engineer	468
	$1,830 per day

Based on the same assumptions regarding the processing rate, this labor will add $4 to $11.50 to the costs of processing each ton of material, for a total cost of $9 to $26.50 per ton of waste treated.

6.4 CONCLUSIONS AND COST SUMMARY

The costs discussed above may be summarized in 12 categories based on the information gathered during the SITE demonstration, the Chemfix cost model, and engineering judgment. These categories are those traditionally used for SITE economic analyses. They are shown in Table 6-2.

Site Preparation Costs

These costs are not included in the Chemfix cost model. They are discussed in Section 6.3.1. An estimate of site preparation costs is $5,000.

Regulatory/Permitting Costs

These costs vary. The costs of compliance with regulatory requirements and permitting will depend on the nature of the site, its proximity to a community, and the state where it is located.

Table 6-2

Estimated Costs of Chemfix Treatment Technology by Category

Cost Category	Subtotal
Site preparation	$6,000
Permitting/regulatory	Variable
Capital equipment	$5 to $15 per ton of raw material
Startup/mobilization Chemfix equipment	$6,000 + $2.50 per round trip mile per truck for
Labor	$9 to $26.50 per ton of raw material
Supplies and consumables	$25 to $35 per ton of raw material
Utilities and miscellaneous expenses	$2 to $4 per ton of raw material
Effluent treatment and disposal	Variable
Residuals and waste shipping, handling, and treatment	Variable
Analyses	Variable
Facility modification/repair/ replacement	Variable
Site demobilization	$6,000
TOTAL UNIT COSTS	**$42 to $80 per ton of raw material**
VARIABLE COSTS	**plus** $20,000 **plus** $2.50 per round trip mile per truck to transport the Chemfix equipment **plus** cost of permitting **plus** cost of effluent treatment **plus** cost of residual disposal **plus** cost of analyses required **plus** cost of facility modification

Startup Costs

Mobilization, setup, and shakedown testing and analysis costs are included in this category. Some of these costs are variable; for example, the cost to transport the Chemfix equipment varies with the distance from Louisiana. This cost comes from the Chemfix model. Also included are the costs to rent equipment such as backhoes, cranes, front-end loaders, and trucks for general site startup work. The estimated costs for this category of work is $6,000 + $2.50 per mile per truck for the round trip in distance from Baton Rouge, Louisiana.

Capital Equipment Costs

Capital equipment costs are associated with both the cost of the Chemfix equipment itself ($2.50 to $7.50 per ton of waste) and the other pieces of equipment necessary to excavate the waste and move it around the site ($2.50 to $7.50 per ton of waste). Total cost for capital equipment is estimated to be $5 to $15 per ton processed, depending primarily on the rate of processing.

Labor Costs

Like capital equipment costs, labor costs are derived from both the Chemfix cost model and an estimate of the labor required to move the wastes to the Chemfix equipment and move the treated product from the process. From the Chemfix cost model, labor costs are $5 to $15 per ton of raw waste processed. Additional labor expected for site work is estimated to cost $4 to $11.50 per ton of waste. Thus, the total labor cost is estimated to be $9 to $26.50 per ton of raw wastes processed.

Supplies and Consumables

The primary consumables used with the Chemfix process are the reagents. The estimated cost for the reagents, from the Chemfix model, is $25 to $30 per ton of raw wastes processed.

Utilities

The cost of utilities is estimated with other miscellaneous operating expenses in the Chemfix cost model. The estimated cost is $2 to $4 per ton of raw waste processed.

Effluent Treatment and Disposal

For the Chemfix process, the only effluent that might need treatment would be generated during the decontamination of personnel and equipment. Therefore, the cost of effluent treatment is expected to be small. The costs will vary with the nature of the site and the contaminants.

Analytical Costs

Analytical costs will also vary, depending on the nature of the contaminants and the regulatory requirements for the site.

Residual and Waste Shipping, Handling, and Transport

Costs of waste shipping, handling, and transporting will vary. If the processed waste can be placed in the pit from which the wastes were excavated, disposal costs will be minimal. If, however, the treated waste must be disposed of in a RCRA Subtitle C facility, costs for residual shipping and disposal could double the costs of treatment.

Facility Modification Cost

Facility modification will vary, depending on the nature and configuration of the site.

Site Demobilization

The cost to demobilize, fill in decontamination pits, and remove equipment is estimated to be $6,000. The cost to transport the Chemfix equipment back to Baton Rouge is included in the cost of mobilization.

The major factors influencing the cost of solidification/stabilization technologies are shown in Table 6-3.

Table 6-3

Major Cost Variables for Site Remedies Involving Solidification/Stabilization Technology

Variable	Comment	Cost Implication
Physical pretreatment needs	If the physical nature of the waste is not compatible with the Chemfix process, pretreatment is necessary.	$2 to $5 per ton
Chemical pretreatment needs	Costs extremely variable based on composition of waste matrix.	-----
Rate of processing	The cost model is very sensitive to the rate of processing. The cost of labor and equipment per ton of raw waste will increase if the process is slower than expected.	Up to $40 per ton
Quantity of waste	The costs of mobilizing the Chemfix treatment unit and preparing the site are fixed costs. Therefore, as the quantity decreases, the cost for mobilization per ton of waste treated increases.	$1 to $30 per ton
Location	The cost of moving the Chemfix treatment unit from Louisiana to the site will increase with an increase in distance from Louisiana.	$1 to $5 per ton
Method of disposal	Placement of the treated material in the excavation pit will have nominal costs. If, however, the nature of the wastes requires disposal in a RCRA Subtitle C facility, costs will be high.	$1 to $175 per ton

APPENDIX A

LIST OF CONTACTS

The principal contacts for further information on the Chemfix process, the SITE demonstration, and the Portable Equipment Salvage Company site are:

EPA ORD:	Mr. Ed Barth Risk Reduction Engineering Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268 (513) 569-7669
CHEMFIX:	Mr. Philip Baldwin Chemfix Environmental Services, Inc. 2424 Edenborn Avenue, Suite 230 Metairie, Louisiana 70001 (504) 831-3600
EPA Region 10:	Mr. John Sainsbury U.S. EPA (HW-093) 1200 6th Avenue Seattle, WA 98101 (206) 442-1196

APPENDIX B

TABLES OF DATA

B.1 TABLES OF DATA

The sampling and analytical contractor for this demonstration supplied the tables which are referenced throughout this chapter. These tables generally present the minimum, maximum, mean value, and relative standard deviation for the parameter under consideration. Because only 3 to 5 data points are available for each test, the median was not included.

It should be noted that these summary tables report the minimum and maximum value in the data set for each parameter, regardless of which sample included that value. Thus, the minimum pH may have been from the same sample as the maximum concentration of lead. Appendix A includes complete data sets with information on the concentrations of each parameter for each sample.

TABLE B-1. TCLP LEACHATE TEST RESULTS FOR AREA A
SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
PCBs by 8080 (ug/L)								
Aroclor 1016	<0.40	<0.40	<0.40	NC	<0.10	<0.11	<0.11	NC
Aroclor 1260	<0.80	<0.80	<0.80	NC	<0.20	<0.22	<0.22	NC
Metals (AA) (mg/L)								
Arsenic	<0.0010	0.010	0.0024	177	0.0030	0.0050	0.0036	25
Metals (ICPES) (mg/L)								
Aluminum	0.20	10	2.4	179	<0.20	1.0	0.50	72
Copper	0.23	71	45	61	0.38	0.71	0.57	24
Lead	0.26	900	610	60	<0.050	<0.050	<0.050	NC
Sodium	1200	1500	1300	8.5	110	1500	1200	51
Zinc	<0.020	25	16	61	<0.020	0.040	0.024	56
Other Chemical and Physical Tests								
pH (pH units)	4.9	9.8	-	-	9.0	11.4	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable.
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-2. TCLP LEACHATE TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	0.064	0.017	162	<0.0010	0.0060	0.0035	64
Metals (ICPES) (mg/L)								
Aluminum	0.20	4.9	2.4	93	<0.20	1.7	0.52	134
Copper	0.040	16	12	58	0.43	0.77	0.54	29
Lead	0.30	1300	880	58	<0.050	6.5	2.5	119
Sodium	1400	1400	1400	0	83	1300	590	109
Zinc	<0.050	43	30	58	<0.020	1.2	0.25	215
Other Chemical and Physical Tests								
pH (pH units)	5.2	9.1	-	-	7.3	11.6	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-3. TCLP LEACHATE TEST RESULTS FOR AREA E
SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	0.015	0.0091	68	<0.0010	0.0030	<0.0020	86
Metals (ICPES) (mg/L)								
Aluminum	0.40	5.6	2.2	111	<0.20	1.1	0.30	149
Copper	0.16	220	120	81	0.16	2.5	0.65	159
Lead	170	1200	740	55	<0.050	169	47	149
Sodium	1200	1500	1400	7.9	71	1300	330	166
Zinc	12	120	71	58	0.020	24	4.8	221
Other Chemical and Physical Tests								
pH (pH units)	4.8	7.0	-	-	6.7	11.7	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-4. TCLP LEACHATE TEST RESULTS FOR AREA F
SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0020	0.014	0.0036	161	0.0040	0.0050	0.0042	11
Metals (ICPES) (mg/L)								
Aluminum	<0.20	15	3.1	215	1.2	2.4	1.9	24
Copper	50	290	120	82	0.49	0.79	0.60	20
Lead	260	540	390	29	<0.050	0.41	0.10	169
Sodium	1400	1500	1400	3.8	1300	1300	1300	0
Zinc	30	73	42	42	<0.020	0.090	0.030	113
Other Chemical and Physical Tests								
pH (pH units)	4.6	5.3	-	-	11.2	11.4	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable.
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-5. TCLP LEACHATE TEST RESULTS FOR REAGENT MIX
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	0.0020	0.0030	0.0023	25
Metals (ICPES) (mg/L)				
Aluminum	0.40	1.3	0.97	51
Copper	<0.020	<0.020	<0.020	NC
Lead	<0.050	<0.050	<0.050	NC
Sodium	1300	1400	1400	4.2
Zinc	<0.020	0.060	0.027	108
Other Chemical and Physical Tests				
pH (pH units)	11.2	11.9	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable.
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-6. ANS 16.1 LEACHATE (2 HOURS) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	<0.0010	0.0010	<0.0010	35
Metals (ICPES) (mg/L)				
Aluminum	<0.20	0.30	0.20	50
Copper	0.030	0.070	0.047	45
Lead	0.10	0.20	0.17	35
Sodium	13	15	14	8.1
Zinc	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests				
pH (pH units)	9.8	9.9	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100

TABLE B-7. ANS 16.1 LEACHATE (7 HOURS) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	<0.0010	0.0010	<0.0010	43
Metals (ICPES) (mg/L)				
Aluminum	0.30	0.60	0.43	35
Copper	<0.020	0.070	0.037	83
Lead	0.20	0.33	0.27	24
Sodium	15	21	17	20
Zinc	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests				
pH (pH units)	10.1	10.2	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100

TABLE B-8. ANS 16.1 LEACHATE (1 DAY) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	<0.0010	0.0020	0.0015	58
Metals (ICPES) (mg/L)				
Aluminum	0.50	1.1	0.73	44
Copper	0.030	0.12	0.063	78
Lead	0.40	0.74	0.62	31
Sodium	19	30	23	25
Zinc	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests				
pH (pH units)	10.7	10.9	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100

TABLE B-9. ANS 16.1 LEACHATE (2 DAY) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	<0.0010	0.0020	0.0015	58
Metals (ICPES) (mg/L)				
Aluminum	0.50	1.1	0.73	44
Copper	0.030	0.11	0.063	66
Lead	0.57	0.97	0.74	28
Sodium	17	28	22	26
Zinc	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests				
pH (pH units)	10.4	10.8	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100

TABLE B-10. ANS 16.1 LEACHATE (3 DAY) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	<0.0010	0.0020	0.0015	58
Metals (ICPES) (mg/L)				
Aluminum	0.50	0.90	0.63	36
Copper	0.030	0.070	0.047	45
Lead	0.46	0.73	0.60	23
Sodium	13	18	15	18
Zinc	<0.020	0.030	<0.020	69
Other Chemical and Physical Tests				
pH (pH units)	10.5	10.6	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100

TABLE B-11. ANS 16.1 LEACHATE (4 DAY) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	<0.0010	<0.0010	<0.0010	NC
Metals (ICPES) (mg/L)				
Aluminum	0.40	0.60	0.50	20
Copper	0.030	0.050	0.043	27
Lead	0.34	0.62	0.50	29
Sodium	8.9	11	9.9	11
Zinc	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests				
pH (pH units)	10.6	10.7	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100

TABLE B-12. ANS 16.1 LEACHATE (5 DAY) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	<0.0010	<0.0010	<0.0010	NC
Metals (ICPES) (mg/L)				
Aluminum	0.50	0.70	0.57	20
Copper	0.020	0.060	0.037	57
Lead	0.36	0.63	0.51	27
Sodium	7.9	11	9.6	16
Zinc	<0.020	0.020	<0.020	43
Other Chemical and Physical Tests				
pH (pH units)	10.4	10.4	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100

TABLE B-13. ANS 16.1 LEACHATE (19 DAY) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	0.0030	0.0030	0.0030	0
Metals (ICPES) (mg/L)				
Aluminum	2.7	5.0	3.7	33
Copper	0.17	0.36	0.24	42
Lead	2.0	2.8	2.5	17
Sodium	58	65	61	5.9
Zinc	<0.020	0.020	<0.020	47
Other Chemical and Physical Tests				
pH (pH units)	10.8	10.9	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100

TABLE B-14. ANS 16.1 LEACHATE (47 DAY) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	0.0051	0.0067	0.0057	15
Metals (ICPES) (mg/L)				
Aluminum	2.3	3.0	2.6	14
Copper	0.18	0.32	0.23	34
Lead	2.6	3.0	2.8	7.1
Sodium	34	48	39	19
Zinc	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests				
pH (pH units)	NA	NA	NA	NA

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100

TABLE B-15. ANS 16.1 LEACHATE (90 DAY) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)				
Arsenic	<0.0010	0.0030	0.0018	69
Metals (ICPES) (mg/L)				
Aluminum	2.1	2.7	2.5	13
Copper	0.23	0.36	0.28	25
Lead	1.6	2.9	2.3	29
Sodium	20	40	29	35
Zinc	0.044	0.049	0.047	5.4
Other Chemical and Physical Tests				
pH (pH units)	10.9	11.0	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100

TABLE B-16. MEP LEACHATE TEST RESULTS FOR AREA C - LEACHATE 1: ACETIC ACID LEACHATE SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	0.023	0.0086	119	<0.0010	0.0090	0.0049	79
Metals (ICPES) (mg/L)								
Aluminum	<0.20	16	4.3	183	<0.20	<0.20	<0.20	NC
Copper	10	54	29	66	0.59	13	3.8	162
Lead	150	1200	660	65	0.51	1200	330	175
Sodium	<1.0	4.0	1.5	112	66	200	110	56
Zinc	8.2	50	23	83	<0.020	24	7.3	156
Other Chemical and Physical Tests								
pH (pH units)	4.4	5.0	-	-	5.8	10.3	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-17. MEP LEACHATE TEST RESULTS FOR AREA C - LEACHATE 2: ACID RAIN LEACHATE SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	0.0020	0.0050	0.0030	47	0.0040	0.012	0.0068	53
Metals (ICPES) (mg/L)								
Aluminum	<0.20	0.20	<0.20	40	<0.20	0.40	<0.20	86
Copper	0.96	2.9	2.4	40	0.14	0.27	0.19	30
Lead	21	120	59	73	0.20	0.64	0.41	58
Sodium	<1.0	1.0	<1.0	40	5.0	10	6.3	40
Zinc	4.5	8.1	6.6	23	<0.020	0.020	<0.020	40
Other Chemical and Physical Tests								
pH (pH units)	5.2	5.7	-	-	9.0	10.5	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-18. MEP LEACHATE TEST RESULTS FOR AREA C - LEACHATE 3: ACID RAIN LEACHATE SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	0.0050	0.0021	95	0.0040	0.019	0.0093	74
Metals (ICPES) (mg/L)								
Aluminum	<0.20	<0.20	<0.20	NC	<0.20	0.60	0.30	82
Copper	0.20	1.6	1.1	58	0.11	0.14	0.12	10
Lead	14	35	25	35	0.37	0.84	0.63	33
Sodium	1.0	2.0	1.5	38	1.0	2.0	1.8	29
Zinc	0.66	3.5	2.6	50	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests								
pH (pH units)	4.8	5.1	-	-	9.8	10.7	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-19. MEP LEACHATE TEST RESULTS FOR AREA C - LEACHATE 4: ACID RAIN LEACHATE SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	0.0020	0.0011	56	0.0050	0.019	0.0093	72
Metals (ICPES) (mg/L)								
Aluminum	<0.20	<0.20	<0.20	NC	<0.20	0.80	0.38	91
Copper	0.040	0.58	0.30	74	0.060	0.11	0.090	24
Lead	8.9	24	16	41	0.20	1.0	0.56	59
Sodium	<1.0	2.0	1.4	55	2.0	3.0	2.8	18
Zinc	0.080	1.4	1.0	62	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests								
pH (pH units)	4.7	5.4	-	-	9.9	10.7	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-20. MEP LEACHATE TEST RESULTS FOR AREA C - LEACHATE 5: ACID RAIN LEACHATE SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	0.0020	0.0014	55	0.0030	0.016	0.0078	74
Metals (ICPES) (mg/L)								
Aluminum	<0.20	0.60	0.28	86	<0.20	0.80	0.40	79
Copper	0.14	0.52	0.28	60	0.060	0.10	0.078	22
Lead	17	42	26	45	0.20	1.2	0.68	60
Sodium	<1.0	2.0	1.0	71	<1.0	2.0	1.1	56
Zinc	0.080	1.4	0.88	64	<0.020	0.030	<0.020	55
Other Chemical and Physical Tests								
pH (pH units)	5.8	7.1	-	-	9.8	10.6	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-21. MEP LEACHATE TEST RESULTS FOR AREA C - LEACHATE 6: ACID RAIN LEACHATE SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	<0.0010	<0.0010	NC	0.0020	0.014	0.0065	81
Metals (ICPES) (mg/L)								
Aluminum	<0.20	<0.20	<0.20	NC	<0.20	0.50	0.25	77
Copper	0.050	0.11	0.070	39	<0.020	0.040	0.028	46
Lead	25	72	40	54	0.10	0.83	0.39	83
Sodium	<1.0	1.0	<1.0	40	<1.0	1.0	<1.0	38
Zinc	0.070	0.52	0.32	63	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests								
pH (pH units)	5.3	7.1	-	-	9.4	10.2	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-22. MEP LEACHATE TEST RESULTS FOR AREA C - LEACHATE 7: ACID RAIN LEACHATE SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	<0.0010	<0.0010	NC	<0.0010	0.011	0.0056	79
Metals (ICPES) (mg/L)								
Aluminum	<0.20	<0.20	<0.20	NC	<0.020	0.40	0.20	88
Copper	<0.020	0.060	0.038	55	<0.020	0.030	0.020	41
Lead	35	79	56	36	0.20	0.67	0.36	62
Sodium	<1.0	<1.0	<1.0	NC	<1.0	1.0	<1.0	40
Zinc	0.060	0.16	0.11	38	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests								
pH (pH units)	6.8	7.4	-	-	9.4	10.2	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-23. MEP LEACHATE TEST RESULTS FOR AREA C - LEACHATE 8: ACID RAIN LEACHATE SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	<0.0010	<0.0010	NC	<0.0010	0.010	0.0041	101
Metals (ICPES) (mg/L)								
Aluminum	<0.20	<0.20	<0.20	NC	<0.20	0.30	<0.20	55
Copper	0.040	0.090	0.058	41	<0.020	0.050	0.035	49
Lead	51	86	72	21	0.20	0.55	0.32	48
Sodium	<1.0	<1.0	<1.0	NC	<1.0	1.0	<1.0	38
Zinc	0.060	0.12	0.10	27	<0.020	<0.020	<0.020	NC
Other Chemical and Physical Tests								
pH (pH units)	7.2	7.6	-	-	9.4	10.2	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-24. MEP LEACHATE TEST RESULTS FOR AREA C - LEACHATE 9: ACID RAIN LEACHATE SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	<0.0010	<0.0010	NC	<0.0010	0.0060	0.0025	105
Metals (ICPES) (mg/L)								
Aluminum	<0.20	<0.20	<0.20	NC	<0.20	<0.20	<0.20	NC
Copper	0.080	0.25	0.15	52	<0.020	0.050	0.033	53
Lead	95	170	140	26	0.20	2.1	0.79	113
Sodium	<1.0	1.0	<1.0	38	<1.0	2.0	1.6	46
Zinc	0.28	<0.40	<0.40	26	<0.020	0.020	<0.020	40
Other Chemical and Physical Tests								
pH (pH units)	6.5	6.9	-	-	7.8	9.3	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-25. MEP LEACHATE TEST RESULTS FOR AREA C - LEACHATE 10: ACID RAIN LEACHATE SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	<0.0010	<0.0010	<0.0010	NC	<0.0010	0.0080	0.0034	102
Metals (ICPES) (mg/L)								
Aluminum	<0.20	0.40	<0.20	86	<0.20	0.20	<0.20	40
Copper	0.11	0.42	0.21	71	0.030	0.16	0.075	77
Lead	60	120	89	30	0.40	15	4.3	166
Sodium	1.0	2.0	1.8	29	1.0	2.0	1.5	38
Zinc	0.13	0.34	0.23	39	0.020	0.040	0.025	40
Other Chemical and Physical Tests								
pH (pH units)	6.9	7.3	-	-	9.0	9.6	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-26. BET LEACHATE (1:4) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	0.0050	0.010	0.0080	33	0.0060	0.012	0.0080	43
Metals (ICPES) (mg/L)								
Aluminum	3.1	7.2	4.8	44	1.5	5.9	3.0	84
Copper	0.050	0.13	0.090	44	0.58	1.1	0.84	31
Lead	0.64	16	5.8	153	320	360	340	6.2
Sodium	7.5	11	8.9	21	370	470	410	12
Zinc	<0.020	0.030	<0.020	69	0.16	0.22	0.19	16
Other Chemical and Physical Tests								
TDS (mg/L)	282	452	370	23	1978	2548	2300	13
pH (pH units)	9.6	10.1	-	-	12.0	12.1	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable.
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-27. BET LEACHATE (1:20) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	0.0080	0.049	0.034	67	0.0060	0.0090	0.0073	21
Metals (ICPES) (mg/L)								
Aluminum	6.8	43	28	68	4.8	5.9	5.3	10
Copper	<0.020	0.060	0.037	69	0.39	0.42	0.40	4.3
Lead	0.76	19	7.7	129	300	360	320	9.9
Sodium	<1.0	3.0	1.8	69	83	100	90	9.9
Zinc	<0.020	0.020	<0.020	43	0.070	0.12	0.097	26
Other Chemical and Physical Tests								
pH (pH units)	9.8	10.2	-	-	11.5	11.6	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable.
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-28. BET LEACHATE (1:100) TEST RESULTS FOR AREA C
SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/L)								
Arsenic	0.0040	0.015	0.0087	66	0.0040	0.0090	0.0070	38
Metals (ICPES) (mg/L)								
Aluminum	1.1	13	5.2	129	3.2	8.3	5.7	44
Copper	0.060	0.080	0.070	14	0.11	0.14	0.12	12
Lead	0.25	94	32	171	140	180	160	13
Sodium	<1.0	3.0	2.2	67	19	25	21	15
Zinc	0.020	0.050	0.033	46	0.040	0.070	0.050	35
Other Chemical and Physical Tests								
pH (pH units)	8.4	10.3	-	-	11.2	11.2	-	-

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable.
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-29. CHEMICAL AND PHYSICAL TEST RESULTS FOR AREA A SOLIDS SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
PCBs and Pesticides by 8080 (mg/kg)								
Aroclor 1016	13	16	14	11	20	28	24	17
Aroclor 1260	93	132	120	18	78	110	95	17
Metals (AA) (mg/kg)								
Arsenic	2.7	24	17	73	19	21	20	5.9
Metals (ICPES) (mg/kg)								
Aluminum	12000	16000	14000	15	13000	16000	14000	11
Copper	15000	20000	18000	15	16000	18000	17000	5.9
Lead	16000	31000	21000	41	17000	26000	21000	22
Sodium	350	740	580	35	2900	4000	3300	19
Zinc	1400	2000	1800	19	1500	1800	1600	9.4
Other Chemical and Physical Tests								
pH (pH units)	7.0	7.2	-	-	11.6	11.7	-	-
Eh (mv)	100	180	140	29	12	61	38	65
Conductivity (umhos/cm)	80	90	83	6.9	4200	5200	4600	12
Water content (%)	13.8	19.6	16.6	18	15.2	17.3	16.3	6.5
Bulk density (g/cm3)	2.0	2.0	2.0	0.3	1.9	1.9	1.9	0.5
Particle size (mm)	3.3	4.7	3.9	19	NA	NA	NA	NA
Specific gravity (g/cm3)	2.7	2.8	2.7	1.3	0.98	1.2	1.1	11
Oil and grease, infrared (mg/kg)	11000	20000	14000	37	20000	23000	22000	7.1
TOC by titration (wt %)	3.7	4.4	4.1	8.6	4.1	4.3	4.2	2.7
Humic acid, solids (wt %)	2.9	8.2	5.2	52	NA	NA	NA	NA
Neutralization potential (meq/g)	NM	NM	NC	NC	2.4	3.1	2.8	14

TABLE B-29. (Continued)

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD

NA: Not Analyzed.

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

NM: No measurable alkalinity.

TABLE B-30. CHEMICAL AND PHYSICAL TEST RESULTS FOR AREA C SOLIDS
SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
PCBs and Pesticides by 8080 (mg/kg)								
Aroclor 1016	47	101	83	26	47	60	53	12
Aroclor 1260	96	234	180	28	120	140	130	9.1
Dioxins and Furans (ug/kg)								
2,3,7,8-TCDD	<0.50	<0.50	<0.50	NC	NA	NA	NA	NA
TCDD	<0.50	<0.50	<0.50	NC	NA	NA	NA	NA
TCDF	<0.50	<0.50	<0.50	NC	NA	NA	NA	NA
PeCDD	<0.50	<0.50	<0.50	NC	NA	NA	NA	NA
PeCDF	<0.50	<0.50	<0.50	NC	NA	NA	NA	NA
HxCDD	<0.50	<0.50	<0.50	NC	NA	NA	NA	NA
HxCDF	13	25	19	32	NA	NA	NA	NA
HpCDD	5.7	8.0	6.7	17	NA	NA	NA	NA
HpCDF	6.9	13	9.5	33	NA	NA	NA	NA
OCDD	8.8	13	10	22	NA	NA	NA	NA
OCDF	4.9	6.3	5.6	13	NA	NA	NA	NA
Metals (AA) (mg/kg)								
Arsenic	40	92	57	36	36	44	42	8.0
Metals (ICPES) (mg/kg)								
Aluminum	14000	17000	16000	7.3	14000	19000	16000	14
Copper	14000	22000	18000	18	12000	15000	14000	8.4
Lead	130000	160000	140000	9.3	40000	64000	52000	17
Sodium	570	690	640	7.0	2300	4300	3300	28
Zinc	3300	6400	4200	30	2300	3100	2600	12

TABLE B-30. (Continued)

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Other Chemical and Physical Tests								
pH (pH units)	6.5	6.7	-	-	11.3	11.5	-	-
Eh (mv)	275	300	290	4.2	-5.0	39	24	74
Conductivity (umhos/cm)	77	200	130	45	2700	3600	3200	14
Water content (%)	10.2	14.2	12.3	16	10.0	14.2	12.5	18
Bulk density (g/cm3)	2.4	2.6	2.5	4.8	1.9	2.0	2.0	4.3
Permeability (cm/sec) A	2.40e-006	2.70e-004	9.00e-005	167	3.10e-007	1.20e-006	6.43e-007	75
Particle size (mm)	4.0	8.3	6.7	35	NA	NA	NA	NA
Specific gravity (g/cm3)	3.0	3.2	3.1	3.0	0.82	0.93	0.87	6.4
Oil and grease, infrared (mg/kg)	30000	36000	32000	7.1	31000	39000	35000	10
TOC by titration (wt %)	3.6	5.3	4.6	14	4.6	5.2	4.9	5.3
Humic acid, solids (wt %)	0.11	3.1	1.0	116	NA	NA	NA	NA
Neutralization potential (meq/g)	NM	NM	NC	NC	4.1	5.8	4.9	15

NA: Not Analyzed.

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

A: Sample results for permeability are expressed in exponential notation (base 10).

NM: No measurable alkalinity.

TABLE B-31. CHEMICAL AND PHYSICAL TEST RESULTS FOR AREA E SOLIDS
SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
PCBs and Pesticides by 8080 (mg/kg)								
Aroclor 1016	253	268	260	3.1	130	210	170	24
Aroclor 1260	241	279	260	7.3	150	230	190	21
Metals (AA) (mg/kg)								
Arsenic	52	64	57	11	38	41	39	3.9
Metals (ICPES) (mg/kg)								
Aluminum	10000	12000	11000	9.1	14000	16000	15000	7.5
Copper	59000	97000	74000	28	31000	37000	33000	9.6
Lead	71000	120000	92000	27	35000	42000	38000	9.5
Sodium	600	620	610	1.9	2500	2600	2500	2.3
Zinc	6800	10000	8000	22	5200	6500	5800	12
Other Chemical and Physical Tests								
pH (pH units)	6.9	7.0	-	-	11.0	11.4	-	-
Eh (mv)	280	290	280	2.0	21	47	33	40
Conductivity (umhos/cm)	200	280	250	18	1700	3400	2500	34
Water content (%)	18.8	19.6	19.3	2.2	12.2	16.3	13.7	17
Bulk density (g/cm3)	2.1	2.3	2.2	3.5	1.8	1.9	1.9	5.0
Particle size (mm)	1.1	1.7	1.3	24	NA	NA	NA	NA
Specific gravity (g/cm3)	2.6	2.8	2.7	3.6	0.89	1.3	1.1	17
Oil and grease, infrared (mg/kg)	51000	100000	75000	33	57000	70000	65000	11
TOC by titration (wt %)	7.4	8.6	7.9	8.2	5.6	8.8	7.4	22
Humic acid, solids (wt %)	0.25	4.4	2.8	80	NA	NA	NA	NA
Neutralization potential (meq/g)	NM	NM	NC	NC	3.1	4.9	3.9	23

TABLE B-31. (Continued)

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD

NA: Not Analyzed.

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

NM: No measurable alkalinity.

TABLE B-32. CHEMICAL AND PHYSICAL TEST RESULTS FOR AREA F SOLIDS
SUMMARY RESULT[a]

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
PCBs and Pesticides by 8080 (mg/kg)								
Aroclor 1016	15	20	17	14	12	15	13	13
Aroclor 1260	274	309	300	6.7	170	220	190	14
Dioxins and Furans (ug/kg)								
2,3,7,8-TCDD	<0.50	<5.0	<5.0	NC	NA	NA	NA	NA
TCDD	<0.50	<5.0	<5.0	NC	NA	NA	NA	NA
TCDF	2.5	6.1	4.3	42	NA	NA	NA	NA
PeCDD	<0.50	<5.0	<5.0	NC	NA	NA	NA	NA
PeCDF	<0.50	16	6.3	136	NA	NA	NA	NA
HxCDD	<0.50	<5.0	<5.0	NC	NA	NA	NA	NA
HxCDF	19	44	35	40	NA	NA	NA	NA
HpCDD	7.4	21	13	51	NA	NA	NA	NA
HpCDF	13	34	23	46	NA	NA	NA	NA
OCDD	8.9	18	14	33	NA	NA	NA	NA
OCDF	7.4	17	12	40	NA	NA	NA	NA
Metals (AA) (mg/kg)								
Arsenic	34	45	39	14	26	29	28	6.2
Metals (ICPES) (mg/kg)								
Aluminum	25000	35000	31000	17	24000	27000	25000	6.9
Copper	31000	36000	33000	7.5	18000	23000	21000	12
Lead	2300	20000	11000	78	9900	10000	9900	0.6
Sodium	240	310	260	15	2500	2700	2600	3.8
Zinc	4900	5500	5100	6.8	3500	3900	3700	5.4

TABLE B-32. (Continued)

	Pretreatment				Posttreatment			
	Minimum	Maximum	Mean	RSD	Minimum	Maximum	Mean	RSD
Other Chemical and Physical Tests								
pH (pH units)	6.8	7.1	-	-	11.6	11.8	-	-
Eh (mv)	270	275	270	1.1	40	63	53	22
Conductivity (umhos/cm)	270	380	340	18	2000	3500	2700	29
Water content (%)	29.8	33.5	31.1	6.6	16.8	20.9	18.6	11
Bulk density (g/cm3)	2.0	2.0	2.0	0.8	1.6	1.6	1.6	0.7
Particle size (mm)	0.53	1.2	0.76	50	NA	NA	NA	NA
Specific gravity (g/cm3)	2.6	2.7	2.7	2.1	0.75	0.79	0.77	2.6
Oil and grease, infrared (mg/kg)	2800	5900	4300	36	13000	18000	15000	16
TOC by titration (wt %)	3.1	3.3	3.2	3.1	3.1	3.5	3.3	6.1
Humic acid, solids (wt %)	0.82	1.1	0.95	15	NA	NA	NA	NA
Neutralization potential (meq/g)	NM	NM	NC	NC	3.1	3.5	3.3	6.4

NA: Not Analyzed.

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.

NC: Not Calculable.

NA: Not applicable, sample was not analyzed for this parameter.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

NM: No measurable alkalinity.

TABLE B-33. CHEMICAL AND PHYSICAL TEST RESULTS FOR REAGENT MIX SOLIDS
SUMMARY RESULT[a]

	Posttreatment			
	Minimum	Maximum	Mean	RSD
Metals (AA) (mg/kg)				
Arsenic	17	19	18	5.6
Metals (ICPES) (mg/kg)				
Aluminum	18000	22000	20000	11
Copper	47	73	56	27
Lead	48	67	58	16
Sodium	1400	1900	1600	15
Zinc	150	200	180	15
Other Chemical and Physical Tests				
pH (pH units)	11.6	11.9	-	-
Eh (mv)	28	54	44	32
Conductivity (umhos/cm)	2700	3900	3200	20
Water content (%)	6.0	8.7	7.5	18
Oil and grease, infrared (mg/kg)	110	240	160	42
TOC by titration (wt %)	<0.050	<0.050	<0.050	NC
Neutralization potential (meq/g)	1.7	4.3	2.9	45

a: Minimum and maximum values reported for different parameters do not necessarily represent identical samples.
NC: Not Calculable.
NA: Not applicable, sample was not analyzed for this parameter.
RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-34. UNCONFINED COMPRESSIVE STRENGTH MEASURED AT 7 DAY INTERVALS FOR TREATED SOILS FROM AREA C.

Analysis Date (a)	Replicate (Sample Box Number)											
	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	R-9	Mean	Std Dev	%RSD
14 Days	243	190	149	141	99	0 (b)	55	103	64	131	64	49
21 Days	182	298	131	166	81	85	52	127	104	136	73	54
28 Days	307	280	116	169	97	68	123	103	27	143	94	66

(a) Number of days after the end of the curing period.
(b) Sample core broke when it was removed from the mold.

TABLE B-35. IMMERSION UNCONFINED COMPRESSIVE STRENGTH MEASURED AT THIRTY DAY INTERVALS FROM TREATED SOILS FROM AREA C.

Analysis Date (a)	Replicate (Sample Box Number)								
	R-1	R-2	R-3	R-4	R-5	R-6	Mean	Std Dev	%RSD
30 Days	307	334	72	109	(b)	62	177	133	75
60 Days	298	313	216	149 (c)	74 (c)	78 (c)	188	105	56
90 Days	54	312	391	110	(b)	151	204	142	70
Mean UCS per box	220	320	226	123	74	97			
Std Dev per box	166	14	184	26	0	55			
%RSD per box	75	4	82	21	0	56			

(a) Number of days after the end of the curing period.
(b) Sample core broke when it was removed from the mold.
(c) Sample contained air voids.

TABLE B-36. WET/DRY WEATHERING OF TREATED SOIL FROM AREA C.

Block Number	Cumulative Corrected Relative Weight Loss (a)												UCS (psi)
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11	Cycle 12	
R-1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38
R-2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	46
R-3	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	6.8

(a) Reported results are the mean of two values.

TABLE B-37. FREEZE/THAW WEATHERING OF TREATED SOIL FROM AREA C.

Block Number	Cumulative Corrected Relative Weight Loss (a)												UCS
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11	Cycle 12	(psi)
R-1	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	9.2
R-2	0.01	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.05	0.08	0.10	0.08	2.1
R-3	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	22

(a) Reported results are the mean of two values.

TABLE B-38 DECHLORINATION TEST RESULTS FOR AREA A SOLIDS

	Pretreatment		15 Day		30 Day		45 Day		60 Day	
	Mean	RSD	Mean	RSD	Mean	RSD	Mean	RSD	Mean	RSD
PCBs by 680 (ug/kg)										
Monochlorobiphenyls	<20	NC	<20	NC	<20	NC	<20	NC	26	106
Dichlorobiphenyls	<20	NC	940	5.2	520	43	860	30	960	46
Trichlorobiphenyls	1800	20	3700	19	2800	32	5200	18	4700	40
Tetrachlorobiphenyls	4400	63	6100	36	4400	28	8100	20	7400	33
Pentachlorobiphenyls	14000	31	9300	25	6300	23	13000	23	13000	19
Hexachlorobiphenyls	31000	16	17000	3.5	10000	8.8	24000	24	23000	22
Heptachlorobiphenyls	21000	13	9600	3.8	6100	7.4	14000	27	13000	26
Octachlorobiphenyls	5600	13	2500	8.2	1500	18	3400	30	2900	42
Nonachlorobiphenyls	600	9.8	150	3.8	<100	55	280	35	330	26
Decachlorobiphenyls	<100	55	<100	NC	<100	NC	<100	NC	<100	NC

NC: Not Calculable.

RSD: Relative Standard Deviation (%) = Standard Deviation/Mean * 100.

TABLE B-39

AMBIENT AIR MONITORING OF PCBs, ng/m³

PCB Congener	Trip Blank	Field Blank	Upwind Areas E, A, F	Area E	Downwind Areas A, F	Area C	Area C-Dup.
mono	<0.06	<0.06	<0.33	<1.3	<0.47	<0.58	<0.57
di	<0.06	<0.06	4.0	11	7.8	4.1	4.8
tri	<0.06	<0.06	1.5	17	15	13	14
tetra	<0.11	<0.11	3.1	3.5	6.6	6.1	5.1
penta	<0.11	<0.11	2.2	<2.5	4.2	1.4	3.4
hexa	<0.11	<0.11	<0.66	<2.5	4.5	2.5	3.7
hepta	<0.17	<0.17	<1.00	<3.8	<1.4	<1.7	<1.7
octa	<0.17	<0.17	<1.00	<3.8	<1.4	<1.7	<1.7
nona	<0.28	<0.28	<1.7	<6.4	<2.3	<2.9	<2.8
deca	<0.28	<0.28	<1.7	<6.4	<2.3	<2.9	<2.8