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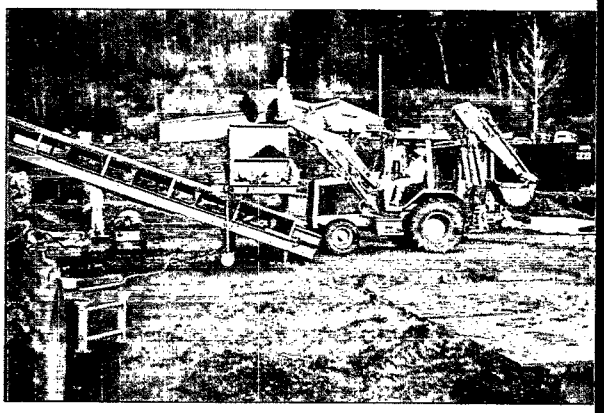
Chemfix Technologies, Inc. Solidification/Stabilization Process

Applications Analysis Report



SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/A5-89/011
May 1991

Chemfix Technologies, Inc. Solidification/Stabilization Process

Applications Analysis Report

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Printed on Recycled Paper

Notice

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Foreword

The Superfund Innovative Technology Evaluation (SITE) 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 meet new, more permanent cleanup standards. The SITE program includes technology demonstrations to provide engineering and cost data on selected technologies.

A field demonstration was conducted under the SITE program to evaluate the Chemfix Technologies, Inc. solidification/stabilization technology. The technology demonstration took place at a Superfund site in Clackamas County, Oregon. The demonstration provided information on the performance and cost of the technology for use in assessing its applicability to this as well as other uncontrolled hazardous waste sites. The demonstration is documented in two reports: (1) a Technology Evaluation Report that describes the field activities and laboratory results; and (2) this Applications Analysis Report, which interprets the data and discusses the potential applicability of the technology.

A limited number of copies of this report will be available at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268. Requests should include the EPA document number found on the report's front cover. When the limited supply is exhausted, additional copies can 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 the Hazardous Waste Collection. Call the SITE Clearinghouse hotline at 1-800-424-9346 or 382-3000 in Washington, D.C., to inquire about the availability of other reports.

E. Timothy Oppelt

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

Abstract

In support of the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Program, this report evaluates the Chemfix Technologies, Inc. (Chemfix), solidification/stabilization technology for on-site treatment of hazardous waste. The Chemfix technology mixes and chemically treats waste material with proprietary additives and water in a patented pug mill to form a more stable material. This report evaluates treatment efficiency and economic data from the SITE demonstration of the Chemfix technology and other past applications.

The Chemfix demonstration was conducted at the Portable Equipment Salvage Company (PESC) site in Clackamas County, Oregon, in March 1989. The PESC site was a transformer and metal salvage facility. Activities at the site left the soil contaminated with polychlorinated biphenyl (PCBs), lead, copper, and other metals. Four on-site areas that differed in soil type and contaminant concentrations were selected to test the Chemfix process on a range of feed materials. Approximately 7 to 8 cubic yards of contaminated soil were excavated from each area and treated. Extensive waste material sampling and analysis were performed before and after treatment so that physical, chemical, and leaching properties could be compared.

According to results from the Toxicity Characteristics Leaching Procedure (TCLP), the Chemfix technology is capable of decreasing the mobility of cadmium, copper, chromium, lead, nickel, and zinc. Lead and copper removals greater than 95 percent were achieved. Available data do not allow conclusions to be drawn regarding the effectiveness of the Chemfix technology in stabilizing organic contaminants or in dechlorinating PCBs. Demonstration data suggest partial dechlorination of PCBs; however, no byproducts of complete dechlorination were found.

The physical stability and durability of the treated waste were demonstrated using unconfined compressive strength (UCS), wet/dry, and freeze/thaw physical testing. The UCS of the treated waste satisfied the EPA guidance level of 50 pounds per square inch (psi) for placement in a landfill. Less than 1-percent weight loss after 12 cycles of wet/dry and freeze/thaw weathering tests indicates treated waste durability in an exposed environment. Treatment results in a volume increase of 20 to 50 percent in the excavated raw waste.

Suitable wastes for Chemfix technology treatment include metals-containing industrial and municipal wastes and soils contaminated with metals. Economic data indicate that the cost of the treatment process is approximately $73 per ton of waste treated, excluding the costs of waste excavation, curing, and storage and final placement or disposal of the treated waste. The total cost of treatment depends on the rate of processing, the need to pretreat wastes, and costs associated with placement or disposal of treated waste.

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Abbreviations

ANS 16.1	American Nuclear Society Leaching Procedure
ARARs	applicable or relevant and appropriate requirements
BET	Batch Extraction Test
BDAT	best demonstrated available technology
C	Celsius
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfm	cubic feet per minute
CFR	Code of Federal Regulations
cm	centimeter
DOT	Department of Transportation
Eh	oxidation/reduction potential
EP	Extraction Procedure Toxicity Test
EPA	Environmental Protection Agency
F	Fahrenheit
FR	Federal Register
ft	foot (feet)
gal	gallon
gpd	gallons per day
hr	hour(s)
HSWA	Hazardous and Solid Waste Amendments to RCRA
kg	kilogram(s)
L	liter
lb(s)	pound(s)
LDR	Land Disposal Restrictions
mg	milligram(s)
mg/kg	milligram per kilogram
mg/L	milligram per Liter
mil	thousandth of an inch
mm	millimeter(s)
mo	month
mv	millivolt(s)
NA	not analyzed
NC	not calculated

NCP	National Contingency Plan
ND	not detected
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PCB	polychlorinated biphenyl
PESC	Portable Equipment Salvage Company
pH	negative logarithm of the hydrogen ion activity
ppm	parts per million
PRC	PRC Environmental Management, Inc.
psi	pounds per square inch
RCRA	Resource Conservation and Recovery Act
SARA	Superfund Amendments and Reauthorization Act
sec	second
SITE	Superfund Innovative Technology Evaluation
SVOC	semivolatile organic compound
SWDA	Solid Waste Disposal Act
TCLP	Toxicity Characteristics Leaching Procedure
TSCA	Toxic Substances Control Act
µg	micrograms
µg/L	micrograms per liter
UCS	unconfined compressive strength
VOC	volatile organic compound
wk	week
wt	weight
yd	yard
yr	year

Conversion of U.S. Customary Units to 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	(degrees Fahrenheit - 32)	=	degrees Celsius

Note:	1000 liters	=	1 cubic meter
	1000 kilograms	=	1 metric ton

Acknowledgments

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Section 1
Executive Summary

The Chemfix Technologies, Inc. (Chemfix) solidification/stabilization technology for high solids-content wastes and soils was demonstrated and evaluated under the Superfund Innovative Technology Evaluation (SITE) program in March 1989. The Chemfix technology is a patented process for ex-situ solidification/stabilization of hazardous wastes using proprietary additives such as soluble silicates and calcium-containing reagents. One of the unique aspects is that the process is designed to treat large quantities of waste in a short time because of high capacity equipment.

The U.S. Environmental Protection Agency (EPA) reviewed data from the SITE demonstration, commercial applications of the technology, and treatability studies conducted under both a Small Business Innovative Research (SBIR) project and the Superfund Analytical Reference Material (SARM) program to draw conclusions regarding applications of this technology at hazardous waste sites with contaminated soils containing metals, semivolatile organics, and polychlorinated biphenyls (PCBs).

Overview of the Site Demonstration

The Chemfix waste solidification/stabilization technology was demonstrated under the SITE program at the Portable Equipment Salvage Company (PESC) site in Clackamas County, Oregon. The PESC site was a transformer and metal salvage facility from the 1960s until 1985. Its operations involved scrapping and recycling power transformers containing PCBs. Activities at the site left the soil heavily contaminated with lead, copper, and PCBs.

For the SITE demonstration, EPA selected four on-site areas that differed in soil type and contaminant concentration in order to test the Chemfix process on a range of feed material characteristics. Approximately 7 to 8 cubic yards of contaminated soil were excavated from each area. The contaminated soil was screened to remove particles greater than 1 inch in diameter. In general, Chemfix equipment cannot process material greater than 1 inch in diameter.

Five Chemfix solidification/stabilization trials were conducted: one calibration run with clean sand and one production run with waste from each of the four designated areas. Each run processed 4 to 6 cubic yards of material. Although the design capacity of the Chemfix equipment used at the SITE demonstration is 40 to 60 cubic yards per hour, the amount of material treated was limited to minimize the quantity of waste that required disposal after the demonstration. The small quantities used for the demonstration may have affected the performance of the equipment by significantly reducing the time available to calibrate and adjust the process equipment.

Raw soil samples taken on the day of the demonstration and treated soil samples taken immediately after processing and curing were tested to provide comparisons of physical and chemical characteristics of the wastes before and after treatment. EPA conducted leaching, physical, chemical, and PCB dechlorination tests to meet the objectives of the SITE demonstration.

Results from the Site Demonstration

The analyses conducted on the raw and treated wastes for this demonstration may be grouped into three classes: leaching 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. Results from the analysis program are presented below.

Leaching Tests

- The Chemfix process treated batches of wastes that contained highly variable amounts of contaminants. The concentration of lead and copper in the soils ranged from 11,000 to 140,000 and from 18,000 to 33,000 mg/kg, respectively. In toxicity characteristic leaching procedure (TCLP) extracts from the raw soil, lead ranged from 390 to 880 mg/L and copper ranged from 45 to 12 mg/L. The mean concentrations of lead and copper in the TCLP extract were reduced 95 to 99 percent by Chemfix solidification/stabilization. These reductions are not corrected for volume dilution by Chemfix reagents.
- Lead leachability indices for the treated material calculated from results of the ANS 16.1 test met the Nuclear Regulatory Commission leachability standard by several orders of magnitude.
- Multiple extraction procedure (MEP) analyses determined the leaching properties of waste using the Resource Conservation and Recovery Act (RCRA) extraction procedure (EP) followed by nine sequential extractions with acidified distilled water. The mean lead concentration in the first extract exceeded the EP toxicity standard of 5 mg/L. Extractions two through ten had much lower mean concentrations of lead, although the mean concentration in the latter extractions showed an upward trend.

Physical Tests

- The unconfined compressive strength (UCS) of the treated material was stable after 14 days of curing.
- The results of UCS tests on samples taken throughout the treatment process showed that the UCS varied considerably between 250 to 300 psi in the first 2 to 4 minutes of

treatment. As treatment progressed, the UCS decreased to an average of approximately 90 psi. It could not be determined if this variation at the early stage of the treatment process was caused by variations in the raw soil, sampling, or testing methods.

- Results from both the wet/dry weathering tests and the freeze/thaw weathering tests indicated that the tested samples had no significant weight loss after 12 cycles (less than 1 percent) compared to the control samples.
- A volume increase of 20 to 50 percent in the excavated raw waste resulted from the addition of Chemfix reagents.

PCB Dechlorination

- PCB extraction data showed evidence of partial dechlorination. The analyses indicated that heavily chlorinated PCB molecules may lose one or more chlorine atoms during treatment. A more detailed analysis of the treated waste failed to reveal products of complete dechlorination. It is not clear to what extent the Chemfix process contributed to PCB dechlorination. Therefore, no conclusions can be drawn regarding the effectiveness of the process in dechlorinating PCBs.
- Air analyses showed that PCB concentrations in the air during treatment were not significantly different from concentrations in the air before treatment began. In addition, there was no difference in the concentrations of PCB upwind and downwind of the treatment operations.

Results from Past Applications

The Chemfix process has been applied to industrial wastes, spiked electroplating waste, Superfund wastes, and municipal waste. Chemfix treated 150 million gallons of dissolved air flotation sludge (K048) contaminated with lead and 6.8 million gallons of electroplating wastewater treatment sludge (F006) in 1985 and 1986, respectively. Based on results from multiple extraction procedures (MEP) testing, these wastes were delisted from EPA's list of hazardous waste after solidification/stabilization by Chemfix. Treatability studies of other industrial wastes indicated that the Chemfix process effectively reduced leaching of arsenic, chromium, cadmium, nickel, and lead to acceptable levels.

In 1987, Chemfix completed work on the Small Business Innovative Research (SBIR) project for EPA. For this study, Chemfix spiked electroplating waste (F006) with metals and solidified/stabilized the waste. The Chemfix process caused a 94 percent reduction of lead in the TCLP extract (from an original concentration of approximately 40 mg/L). Mobility of arsenic, barium, selenium, silver and vanadium were unaffected by the Chemfix treatment, and the mobility of antimony and mercury increased. The effect of treatment additives was also evaluated in the SBIR.

Prior to the SITE demonstration, the Chemfix process was tested on Superfund Analytical Reference Material (SARM), a synthetic soil. Concentrations of cadmium, copper, chromium, nickel, lead, and zinc in TCLP extracts from untreated SARM were approximately 28, 192, 7, 21, 33, and 525 mg/L, respectively. The concentrations of these metals in the TCLP extract from Chemfix-treated material were reduced 99 percent.

The Chemfix process has been used to solidify municipal sewage sludge. Treated sludge has been used as daily cover and final capping material for sanitary landfills.

Conclusions

The following conclusions regarding applications of the Chemfix technology for ex-situ stabilization of waste were drawn from SITE demonstration data and other available data:

- Based on TCLP results, the Chemfix technology is capable of decreasing the mobility of cadmium, copper, chromium, lead, nickel, and zinc.
- Based on TCLP tests from previous treatability studies, antimony, barium, mercury, selenium, silver, thallium, and vanadium are more difficult for the Chemfix process to immobilize.
- Treatment data for arsenic were ambiguous: the extent to which arsenic was fixed by the Chemfix process varied between applications. Therefore, it is difficult to draw specific conclusions from arsenic data.
- The available data do not allow conclusions regarding the effectiveness of the Chemfix technology in stabilizing organic contaminants or in dechlorinating PCBs. SITE demonstration data suggest partial dechlorination of PCBs; however, byproducts of complete dechlorination were not found.
- Waste material must be screened or reduced in size to less than 1 inch in diameter before processing with Chemfix equipment.
- Physical properties of Chemfix-treated material indicate durability in an exposed environment.
- Highly variable raw waste feed characteristics can result in a treated product that is variable in quality.
- The cost of the treatment process is $73 per ton of raw waste treated. This estimate is based on cost information supplied by Chemfix and the materials-handling costs incurred during the SITE demonstration. This estimate does not include the cost of waste excavation, curing, storage, and final placement or disposal of the product. The total cost of treatment depends on the rate of processing, the need to pretreat wastes to remove other contaminants, and costs associated with placement or disposal of the treated waste.
- The total volume increase resulting from treatment with Chemfix reagents is between 20 and 50 percent of the excavated raw waste.

The Chemfix solidification/stabilization technology is an economical remedial action alternative for decreasing mobility of lead, copper, zinc, and other metals in contaminated soils. Site-specific factors such as contaminant concentration, presence of organic constituents, metal speciation, soil conditions, ground-water conditions, and possible pretreatment needs make site-specific treatability studies necessary before application of the technology at a particular hazardous waste site. Other leaching tests may be necessary to determine the long term effectiveness of solidification/stabilization processes.

Section 2
Introduction

This section describes the SITE program, discusses the purpose of the Applications Analysis Report, and describes the Chemfix technology. A list of key personnel who can be contacted for additional information is provided in Appendix A.

Purpose, History, and Goals of the Site Program

The Superfund Amendments and Reauthorization Act of 1986 (SARA) directed the U.S. Environmental Protection Agency (EPA) to establish an "Alternative or Innovative Treatment Technology Research and Demonstration Program." In response, United States EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) established a formal program called the Superfund Innovative Technology Evaluation (SITE) Program. The SITE Program accelerates development and use of innovative cleanup technologies at hazardous waste sites across the country.

The SITE Program consists of the following:

- Demonstration Program
- Emerging Technologies Program
- Measurement and Monitoring Technologies Development Program
- Innovative Technologies Program
- Technology Transfer Program

This document was produced as part of the SITE Demonstration Program. The objective of the SITE Demonstration Program is to develop reliable engineering performance and cost data on innovative technologies so that potential users can evaluate each technology's applicability to a specific site as compared to other alternatives. Demonstrations are conducted at hazardous waste sites (usually Superfund sites) or under conditions that closely simulate actual wastes and conditions. This assures the usefulness and reliability of information collected.

Data collected during a demonstration are used to assess the performance of the technology, the potential need for pre- and post-treatment processing of the waste, applicable types of waste and media, potential operating problems, and approximate capital and operating costs. Demonstration data can also provide insight into long-term operating and maintenance costs and long-term risks.

Technologies are selected for the SITE Demonstration Program through annual requests for proposal (RFPs). Proposals are reviewed by OSWER and ORD staff to determine the technologies with the most promise for use at hazardous waste sites. Technologies are selected following interviews with the developers. To be eligible, technologies must be at the pilot or full-scale stage, must be innovative, and must offer some advantage over existing technologies. Mobile technologies are of particular interest. Cooperative agreements between EPA and the developer set forth responsibilities for conducting the demonstration and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is expected to pay the costs to transport, operate, and remove the equipment. EPA is responsible for project planning, sampling and analysis, quality assurance and quality control, preparing reports, and disseminating information.

Documentation of Site Demonstration Results

The results of the Chemfix SITE demonstration are incorporated in two documents: the Technology Evaluation Report and the Applications Analysis Report. The Technology Evaluation Report provides a comprehensive description of the demonstration and its results. It is intended for engineers making a detailed evaluation of the technology for a specific site and waste situation. These technical evaluators seek to understand in detail the performance of the technology during the demonstration and the advantages and risks of the technology for the given application. This information will be used to produce conceptual designs in sufficient detail to make preliminary cost estimates for the demonstrated technology.

The Applications Analysis Report is intended for decision-makers responsible for implementing specific remedial actions. The basic use of the Applications Analysis Report is to assist in determining whether the specific technology should be considered further as an option for a particular cleanup situation. The report discusses advantages, disadvantages, and limitations of the technology. Costs of the technology for different applications are estimated based on available data for pilot- and full-scale applications. The report discusses factors, such as site and waste characteristics, that have a major impact on cost and performance. If a candidate technology appears to meet the needs of site engineers, a more thorough analysis can be conducted. This analysis will be based on the Technology Evaluation Report, the Applications Analysis Report, and information from remedial investigations for the specific site.

Purpose of the Applications Analysis Report

To encourage general use of demonstrated technologies, EPA provides information on the applicability of each tech-

nology to certain sites and wastes, other than those already tested, and studies the costs of these applications. Available information is presented in the Applications Analysis Report. This report synthesizes available information on a technology and draws reasonable conclusions about its broad-range applicability. The Applications Analysis Report is very useful to those considering a technology for Superfund cleanups; it represents a critical step in the development and commercialization of a treatment technology.

Each SITE demonstration will evaluate the performance of a technology in treating a particular waste found at the demonstration site. To obtain data with broad applications, attempts will be made to select waste frequently found at other Superfund sites. In many cases, however, waste at other sites will differ in some way from the waste tested. Thus the successful demonstration of a technology at one site does not ensure that it will work equally well at other sites. Data obtained from the demonstration may have to be extrapolated to estimate the total operating range over which the technology performs satisfactorily. This extrapolation should be based upon both demonstration data and other information available about the technology.

The amount of data available for evaluation of an innovative technology varies widely. Data may be limited to laboratory tests on synthetic wastes or may include performance data on actual wastes treated with pilot- or full-scale treatment systems. In addition, there are limits to conclusions that can be drawn from a single field demonstration. A successful field demonstration does not necessarily ensure that a technology will be widely applicable or will be fully developed on a commercial scale.

Chemfix Process Description

Solidification/stabilization technologies are employed to decrease the rate at which chemical contaminants migrate into the environment. This is accomplished by reducing or eliminating contaminant leaching through a chemical process in which pollutants are chemically bound or entrapped, or both, in a solid matrix. This generally improves handling and physical characteristics of hazardous wastes.

Solidification of waste material in a solid matrix is a physical process that reduces the surface area available for leaching. Stabilization implies a chemical process that causes contaminants to be less mobile. Chemical solidification/stabilization of hazardous wastes is typically achieved by mixing the waste with cement, lime, kiln dust, flyash, or some other material. The performance of waste-solidifying formulations varies widely according to the composition of the mixture and the contaminants of concern.

The Chemfix process is a technology with patented additives originally formulated in the early 1970s. Chemfix also holds a patent on specific process mixing equipment used to solidify/stabilize wastes. Chemfix has applied the process and formulations to a wide variety of wastes. Originally, the process was used primarily to solidify/stabilize liquid wastes and semi-liquid wastes into a soil-like material suitable for transport or land disposal. After the passage of the Resource Conservation and Recovery Act (RCRA) in 1976 and the regulations implementing RCRA, the process was used to limit contaminant mobility in hazardous wastes.

The Chemfix solidification/stabilization process can treat solids, liquids, and sludges ranging between 8 and 75 percent solids by weight. Water and two reagents developed by Chemfix (CHEMSET I-20 dry reagent and CHEMSET C-220 liquid reagent) are added to waste material to achieve solidification/stabilization. The Chemfix technology processes waste in what Chemfix terms a continuous process. The following process description is based primarily on information provided by Chemfix.

Process Chemistry

The Chemfix process is based on use of a proprietary family of polysilicates (CHEMSET C-220) and dry calcium-containing reagents (CHEMSET I-20). The two-phase inorganic chemical system reacts with polyvalent metal ions in the waste, certain other waste components, and itself to produce a chemically and physically stable solid matrix (Chemfix, 1987). The matrix-forming chemistry is assisted as needed by reaction-promoting 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 of base, neutral, and acid (BNA) extractable organics with high molecular weights.

According to Chemfix, the solidified matrix 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).

Three classes of interactions occur during the solidification/stabilization process. First are the very rapid reactions among CHEMSET polysilicates, certain reaction promoters, and metal ions. These produce insoluble metal silicates that cannot be resolubilized and are resistant to breakdown under severe environmental conditions. The second class of interactions occurs between polysilicate molecules and reactive components within the dry reagent to produce a gel structure. The gel holds ions in place by chemical and physical bonding mechanisms. Other waste components such as oils are also trapped in the structure and thereby immobilized. The third class of interactions occurs among the dry reagent, the waste, and water (both free and contained) as the dry reagent undergoes a series of hydrolysis, hydration, and neutralization reactions (Chemfix, 1987).

Principal Treatment Operations

A typical Chemfix soil treatment system consists of a feed hopper, a primary conveyor, a weigh feeder, a high-speed shear process mixer (homogenizer), a dry reagent storage tank, a liquid reagent storage tank, two alarm and control panels, a high shear process mixer, and other associated equipment (Figure 2-1). The various constituents of the treatment system are connected both physically and electronically; the actual arrangement of the equipment may vary with site

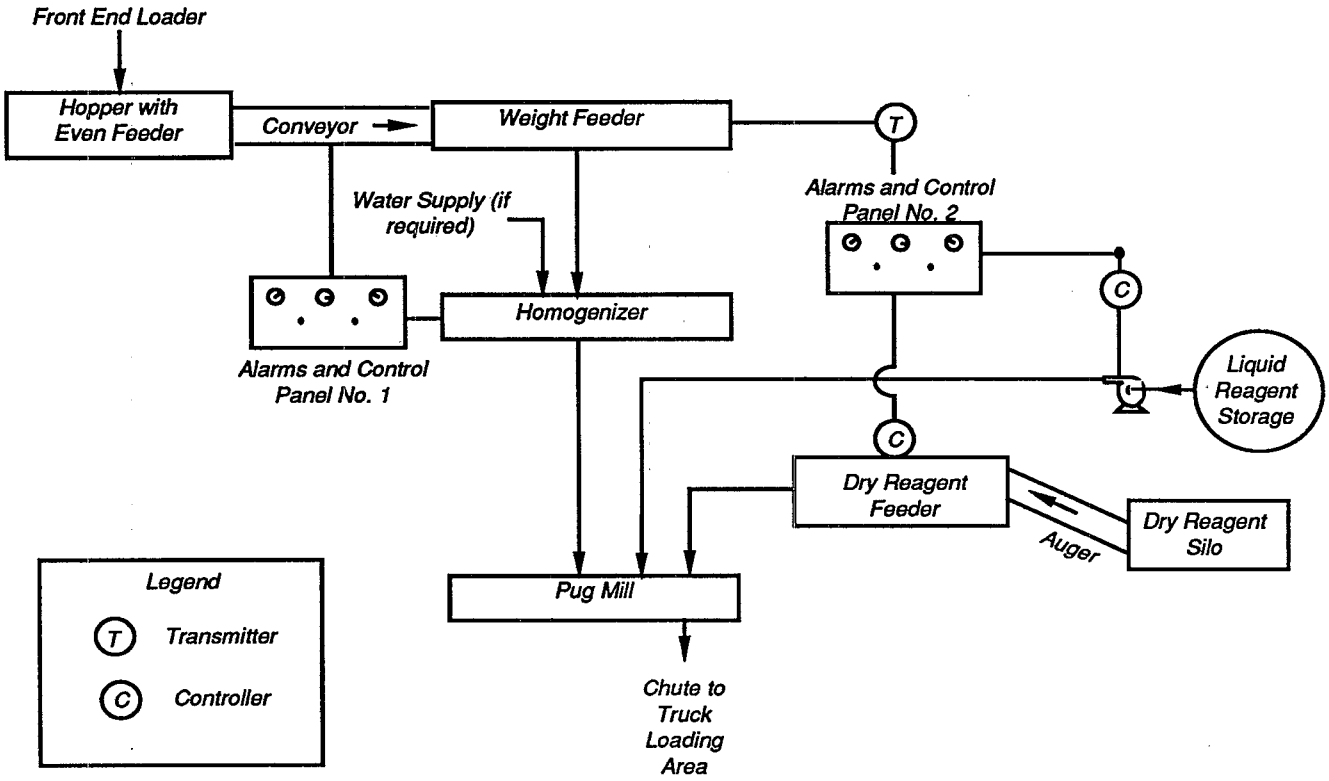

Figure 2-1. Chemfix Technologies, Inc., high solids treatment system block process flow diagram.

conditions. The configuration used at the Portable Equipment Salvage Company (PESC) site was designed to handle 40 to 75 cubic yards of material per hour. The system used at the PESC site was operated by two people, one person to operate each alarm and control panel.

The Chemfix solidification/stabilization process is best described by tracing the flow of soil through the system. The process is divided into two phases: (1) waste preparation (operations before the addition of Chemfix reagents) and (2) waste treatment (all subsequent operations).

The first step in the waste preparation phase is the transfer of soil from the soil storage area to the soil feed hopper, which has a 15- to 20-cubic yard capacity. Feed material is transferred by the variable speed primary conveyor to the weigh feeder. The weigh feeder continuously meters contaminated material by weight into a high-speed shear process mixer (homogenizer). The weigh feeder, which can deliver up to 150,000 pounds per hour of waste material, electronically regulates the amount of water added to the homogenizer. The water flow rate depends on the weight of feed material entering the homogenizer. The ratio of added water to feed material can be set by adjusting the flow controller to obtain the optimum soil-to-water ratio by weight. The speed of the homogenizer is controlled from the alarm and control panel.

The second phase of the process, waste treatment, begins as the soil-water mixture is transferred from the homogenizer to the high shear process mixer. The dry and liquid reagents are added to the process mixer, which uses a Chemfix-designed pug mill to blend the ingredients. The dry reagent feeds into the process mixer through a dry reagent feeder from the storage silo. The liquid reagent is pumped from the storage tank to the pug mill. The feed rates for dry and liquid reagents are regulated by the amount of material fed to the homogenizer, which transmits an electronic weight signal to the controllers of the dry reagent feed auger and the liquid reagent feed pump. The reagents, soil, and water remain in the process mixer until all the ingredients are blended into a pasty mixture. The mixture moves from the receiving end of the process mixer to the discharge chute as mixing occurs. The final product is then discharged from the process mixer into a storage bin and transported to a designated area for curing.

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

Innovative Features of the Chemfix Process

The Chemfix treatment system is a mobile, self-contained, continuous processing unit mounted on a flatbed trailer. The innovative features of the turn-key system are the proprietary reagents and the high capacity pug mill mixer patented by Chemfix.

Chemfix Process Limitations

The Chemfix process has been used to treat a variety of wastes, including contaminated soils, mine tailings, municipal and industrial sludges, and petrochemical wastes. However, the Chemfix process has limitations. It is generally not applicable, without pretreatment, 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
- Waste feed material greater than 1 inch in diameter
- pH less than 2 or greater than 12

The Chemfix process requires enough space to accommodate all its treatment equipment. For example, for the SITE demonstration, Chemfix required a 25 by 40-foot, curbed, concrete pad for the processing unit and a 50 by 150-foot, graded, gravel-covered area for loading and parking. Additional space is required to store treated material during curing and prior to final disposal.

Section 3
Technology Applications Analysis

This section addresses the applicability of the Chemfix solidification/stabilization process to hazardous waste sites. Evaluations herein are based primarily on the results of the SITE demonstrations, which are presented in detail in the Technology Evaluation Report. This section also draws upon data from treatability studies conducted as part of the Small Business Innovative Research (SBIR) and Superfund Analytical Reference Material (SARM) projects, as well as information supplied by Chemfix on several industrial projects using the technology. Developer's claims regarding the applicability and performance of the Chemfix technology are included in Appendix B.

The successful application of a hazardous waste treatment technology can be judged by the ability of the technology to satisfy applicable or relevant and appropriate requirements (ARARs). The effectiveness of the technology and the regulatory requirements are addressed below.

Technology Evaluation

A summary of SITE demonstration information, including site characteristics, waste characteristics, and a review of the Chemfix system's performance, is presented in Appendix C. Past applications are presented in Appendix D.

The successful application of solidification/stabilization treatment technology depends on at least three criteria: (1) the chemistry of the wastes must match the performance range of the technology; (2) the physical characteristics of the wastes must meet the materials handling capability of the technology; and (3) the site must be able to support the necessary equipment, utilities, and supplies. In addition, the product must meet disposal requirements established by law and regulation.

Effectiveness Of The Chemfix Solidification/ Stabilization Process

An important requirement for successful application of the Chemfix technology is compatibility between the chemistry of the treatment process and the chemistry of the waste to be processed. The following subsections focus on groups of contaminants that may be considered similar with respect to the applicability of the Chemfix technology. Because of variations in results for different waste matrices and contaminants, the technology's performance is difficult to predict without some bench-scale testing. Treatability studies are recommended before large-scale applications are considered.

Cadmium, Copper, Chromium, Lead, Nickel, and Zinc

Data from the SBIR project and a Superfund site showed reductions of 94 to 99 percent in concentrations of lead, copper, and zinc in the TCLP extract from treated waste. The TCLP extract from untreated wastes ranged from 4 to 38 mg/L lead, 23 to 176 mg/L copper, and 158 to 530 mg/L zinc. In addition, the SBIR study, the SARM project, and a Superfund site cleanup indicated that the Chemfix process achieved 99-percent reductions in concentrations of cadmium, chromium, and nickel in the TCLP extract from treated wastes.

Sixty-five percent of the samples of treated waste tested from all areas of the PESC site satisfied the SITE demonstration standards of 0.51 mg/L of lead in the TCLP extract (based on electroplating waste). Seventy percent of the samples tested satisfied the arbitrary soil demonstration standard of 5.0 mg/L of lead in the TCLP extract. Although a substantial fraction of the samples did not meet the demonstration standards, the raw waste at the SITE demonstration contained very high concentrations (up to 14 percent) of lead. It should be mentioned that soils with lead concentrations at this level should be considered for lead recovery operations. Lead concentrations in TCLP extract from treated waste were significantly less (94 to 99 percent) than those from the untreated waste.

Although treatment results indicate that lead leachability is substantially decreased, the amphoteric nature of lead should be considered in any Chemfix applications. Lead hydroxides are insoluble between pH 8 and 10.5 but become very soluble as the pH increases past 11. The potentially high alkalinity of solidified/stabilized waste material suggests that, at very high concentrations, lead may leach from the solid matrix. The potential for lead leaching increases if metal hydroxides are formed and the material is disposed of in an area with leachate or ground water that is neutral or alkaline (for example, in a disposal unit dedicated to metal-containing wastes). Chemfix claims that metal silicates rather than metal hydroxides are formed, thereby eliminating the potential problem of increased solubility at high pH.

Arsenic, Antimony, Barium, Mercury, Selenium, Silver, Thallium, and Vanadium

The effectiveness of the Chemfix technology for stabilizing arsenic depends on waste-specific chemistry. Data from treatability tests and the SARM project suggest effective solidification/stabilization of arsenic. However, the SBIR study showed difficulties in stabilizing arsenic, antimony, barium, mercury, selenium, silver, thallium, and vanadium. Although

contaminant-specific additives may help solidify/stabilize certain metals, site-specific bench- and pilot-scale analyses are required before applying the Chemfix technology to wastes contaminated with these metals.

Organic Pollutants

Although Chemfix claims limited success in reducing concentrations of organic contaminants in treated waste material, the SITE demonstration was unable to confirm such reduction. Volatile organic compounds (VOCs) were not present in significant concentrations in the untreated wastes at the PESC site. Semivolatile organic compounds were found only in low concentrations and the data do not show that levels were reduced by the treatment process.

The Chemfix treatment process requires a significant amount of mixing to incorporate reagents into wastes, which may cause heat generation. Therefore, VOCs may be released to the atmosphere during treatment. If significant concentrations of organic pollutants are present in the waste material, another technology may be required to pretreat the waste in order to eliminate organic contaminants.

One objective of the SITE demonstration was to determine the fate of polychlorinated biphenyls (PCBs) during the treatment process. Careful analysis of the wastes before and after treatment indicated no reduction in the total concentration of PCBs. However, the data did show some evidence of partial dechlorination of PCBs. It could not be determined whether this was the result of aging, physical mixing, or chemical reagents. The mobility of PCBs before and after treatment could not be analyzed because PCBs did not leach from raw wastes during the TCLP extraction procedure.

Matrix Effects

High concentrations of solid organic material in the waste may interfere with the performance of cement-based solidification/stabilization technologies. During the SITE demonstration, the Chemfix technology was applied to wastes with moderate organic content (3 to 8 percent total organic content). These concentrations did not appear to affect the ability of the process to stabilize inorganic contaminants in the waste material. However, there is evidence that indicates certain chemicals such as phenol at concentrations of 8 percent can decrease the UCS of the material by as much as 96 percent (HWC, 1988). Therefore, the biggest concern of organic content in waste treated by solidification/stabilization may be the effect on the physical properties of treated waste.

Past industrial applications of the Chemfix process include treatment of large quantities of dissolved air flotation sludge (K048) in order to remove the waste from EPA's list of hazardous wastes. This waste contains high concentrations of organic material. However, data available from that Chemfix application are insufficient to reach a conclusion regarding the effect of organic material on the treatment process.

Water Content

In the past, the Chemfix technology was applied primarily to liquid waste and sludge. One innovative feature of the SITE demonstration for this technology was its application to contaminated soil. Because the treatment process requires a high water content, water must be added when applying the technology to relatively dry soil.

At the SITE demonstration, several of the treatment runs were performed on waste and reagent mixtures containing less than 15 percent water. The optimal water content for this application of the Chemfix process was 25 percent. The solidification/stabilization results of the SITE demonstration may be improved with higher water content; however, increasing water content, together with the Chemfix reagents, may increase the volume expansion of the treated material.

Site Characteristics

Chemfix set up a full-scale, mobile unit on a 2-acre site for the SITE demonstration. Restricted site size can limit the quantity of material that can be prepared for treatment in advance and the quantity of product that can be cured on-site. Minimum requirements for a Chemfix treatment operation with a capacity of 75 to 100 cubic yards per hour, including equipment, decontamination facility, and health and safety requirements, are as follows:

- A 25- by 40-foot concrete pad for the process unit. This unit is delivered to the site on three 40-foot trailers and must be assembled on-site.
- A 50- by 150-foot graded pad covered with gravel for parking, loading, and general work.
- A decontamination facility for trucks and equipment working in the contaminated zone.
- A decontamination facility for personnel working in the contaminated zone.
- An area for storing raw waste from the time it is excavated until it is processed. This area includes space for a pretreatment unit for screening or crushing if the waste contains particles larger than 1 inch in diameter.
- A storage area for treated product while it cures if it is to be cured on-site before final disposal. Chemfix's experience and results of the SITE demonstration indicate that treated material requires 72 hours to cure. Therefore, the storage area for the treated product should be sized for several days of production.

Logistical support required for the Chemfix technology includes a source of electricity (480-volt, 3-phase, 60-Hz power supply at 200 Amps), process water at 60 psi, potable water and sanitary facilities for workers, and a telephone line.

Materials Handling

Most Superfund sites contain some form of contaminated soil; therefore, this discussion of materials handling focuses on Chemfix operations required to treat high solids-content wastes such as soil. Waste material must be excavated, stockpiled, treated, partially cured, and land-disposed, at a minimum. In addition, other operations may be required, such as screening or grinding to reduce particle size, additional mixing to increase the homogeneity of wastes and incorporate reagents, and emissions control for volatile pollutants.

Particle Size

The Chemfix treatment process requires that raw waste be comprised of particles no larger than 1 inch in diameter.

Therefore, most soils containing debris must be screened before treatment. Screening is relatively easy to accomplish with dry soils; however, moist or sticky material is difficult to screen. Moreover, at the SITE demonstration the screening operation allowed objects such as long wires to enter and clog treatment equipment.

Screening has the disadvantage of creating sidestream waste (large particles) that are inappropriate for treatment with the Chemfix process. At the SITE demonstration, such material amounted to 40 percent of the soil excavated. One option is to crush the material into smaller particles to make it suitable for application of the Chemfix technology. Another option is to use a different technology, such as soil washing or extraction, for larger particles as a pretreatment operation. The option selected for larger particles depends on the nature and quantity of the wastes considered for treatment.

Reagent Delivery and Mixing

Results from the SITE demonstration indicated that products of the Chemfix treatment process varied significantly in chemical composition and physical strength. During some of the test runs, waste visually appeared to be significantly underdosed with reagent and water compared to the theoretical doses determined from preliminary sampling.

Variations in the composition of raw waste are partially responsible for variability in the treated waste. If waste material exhibits significant variability, an additional mixing step should be considered as a pretreatment operation to improve the consistency of the treated waste.

Emissions Control

Control technology for emissions from the Chemfix technology exists for waste materials similar to the PESC site wastes. Applications involving wastes contaminated with metals do not present a volatilization problem. Dust emissions from soils containing a large fraction of fine particles are the primary concern. Metals and semivolatile organics adsorbed onto fine particles present an inhalation risk to workers. Dust emissions are generally controlled with traditional dust suppression techniques such as application of water or synthetic materials to strengthen adhesion between soil particles.

If the Chemfix technology is used to treat wastes with significant levels of volatile organic contaminants, especially volatiles, additional controls (such as a negative-pressure air system) may be necessary to prevent releases during excavation, screening, and mixing phases of the treatment process. The exothermic nature of the chemical stabilizing process releases heat that accelerates emissions of volatile contaminants.

Disposal Requirements

After wastes are solidified/stabilized using the Chemfix process, a volume of material larger than the original excavated waste volume requires disposal. According to data from the SITE demonstration, the treated product will be 20 to 50 percent greater in volume than the untreated waste. The volume expansion ratio is a site-specific factor, however, and these percentages represent only a single application.

The cost-effectiveness of the Chemfix process depends in part on whether treated material may be disposed of as a nonhazardous waste. If the waste originates only as a characteristic waste, and if the treatment process renders it nonhazardous by removing all hazardous characteristics, the material may be disposed of as a solid waste subject only to requirements for municipal and solid wastes defined by state regulations. However, if the waste remains hazardous after treatment, either because the waste remains a listed waste or is derived from a listed waste, or the waste remains of regulatory concern, it must be disposed of as a hazardous waste at a RCRA Subtitle C facility. The cost of such disposal will significantly increase the total cost of Chemfix treatment.

In addition to the treated material, other waste streams must be considered. Large particles screened during the treatment process and water used to decontaminate personnel and equipment must be treated and disposed of. The decontamination water may be a liquid hazardous waste subject to treatment and disposal requirements different than those that apply to solid waste.

Regulatory Requirements

This section discusses federal regulatory requirements for solidification/stabilization technology and analyzes these requirements in view of SITE demonstration results. State and local regulatory requirements, which may be more stringent, will also have to be addressed by users of the technology.

Comprehensive Environmental Response, Compensation and Liability Act

The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) authorizes the federal government to respond to releases or potential releases of any hazardous substance into the environment as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or the environment.

SARA amended CERCLA and directed EPA to

- Use remedial alternatives that permanently and significantly reduce the mobility, toxicity, or volume of hazardous substances, pollutants, or contaminants;
- Select remedial actions that protect human health and the environment, are cost-effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible; and
- Avoid off-site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist (Section 121[b]).

As part of the requirements of CERCLA, EPA prepared the National Contingency Plan (NCP) for hazardous substance response. The NCP (codified in 40 CFR Part 300) delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination. The NCP includes solidification as a possible, cost-effective technology for remediation of contaminated soils and sediments (Section 300.70). The preference under SARA for permanent solutions that reduce mobility, toxicity, or volume applies to use of solidification/stabilization technolo-

gies at CERCLA sites. Although solidification/stabilization technologies do not reduce waste volume and may not reduce toxicity, significant reductions in mobility are achievable.

EPA is required to review any remedial action in which hazardous substances, pollutants, or contaminants remain at the site. A remedial action in which hazardous substances are treated by solidification/stabilization and are disposed of at the site may need to be reviewed by EPA every 5 years to ensure continued protection of human health and the environment.

Contaminated soil and debris are the primary types of waste at most CERCLA sites. If the soil and debris contain hazardous wastes subject to RCRA Land Disposal Restrictions (LDRs), they may need to be treated to comply with LDR treatment standards or a variance must be obtained from EPA.

Resource Conservation and Recovery Act

RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. Wastes defined as hazardous under RCRA include characteristic and listed wastes.

Several RCRA requirements may apply to hazardous waste treatment by solidification/stabilization and to the disposal of treated product. RCRA requires that solidified/stabilized waste considered for land disposal contain no free liquids. The presence or absence of free liquids should be demonstrated using the paint filter liquids test (EPA Method 9095). Wastes treated by the Chemfix process usually will not contain free liquids.

In addition, according to EPA land disposal guidance for stabilized waste (EPA, 1986a), the UCS of solidified/stabilized waste must equal or exceed 50 psi. Based on results from the SITE demonstration and other applications, waste treated by the Chemfix process contain no free liquids and have a UCS greater than 50 psi.

If the waste treated is a listed waste, the treatment product will be considered a listed waste unless RCRA delisting requirements are met. Delisting requires that a demonstration be made that the waste material has been adequately solidified/stabilized. A successful petition for delisting must clearly demonstrate that the treated waste does not exhibit any hazardous characteristics (such as corrosivity, igniteability, reactivity, or EP toxicity). The multiple extraction procedure (MEP) is one method for testing the leaching properties of waste treated by Chemfix to demonstrate that the waste has been adequately solidified/stabilized. EPA delisted 150 million gallons of dissolved air flotation sludge and 6.8 million gallons of electroplating wastewater treatment sludge following solidification/stabilization by Chemfix.

For both CERCLA and RCRA corrective actions, treated waste produced by the Chemfix process may be subject to LDR requirements if it is hazardous and land disposed. Several LDR compliance alternatives exist for disposing of the treated waste if they are hazardous: (1) comply with the LDR that is in effect; (2) comply with the LDRs by choosing one of the LDR compliance alternatives (for example, treatability variance, no migration petition); or (3) invoke an applicable, relevant, and appropriate requirement (ARAR) waiver (this option would only apply to on-site CERCLA disposal).

EPA established treatment standards for listed and characteristic hazardous waste based on the Best Demonstrated Available Technology (BDAT) determined for each waste. Under RCRA, hazardous wastes are restricted from land disposal unless established treatment standards have been met. The established treatment standards may be applicable to waste treated by the Chemfix process if the waste treated is similar to a specific listed or characteristic wastestream. However, RCRA provides for a treatability variance under 40 CFR 268.44 in which alternate treatment standards may be utilized. Because soil and debris at Superfund sites often do not meet narrowly defined waste categories, EPA established guidance on applying a treatability variance to the treatment of soil and debris from Superfund sites (EPA, 1989)

Toxic Substances Control Act

Disposal of PCBs is regulated under Section 6(e) of the Toxic Substances Control Act of 1976 (TSCA). PCB treatment and disposal regulations are described in 40 CFR Part 761. Materials containing PCBs in concentrations between 50 and 500 parts per million (ppm) may either be disposed of in TSCA-permitted landfills or destroyed by incineration at TSCA-approved incinerators; at PCB concentrations greater than 500 ppm, the material must be incinerated. Therefore, soil with PCB concentrations of up to 500 ppm may be suitable for solidification. Where state standards are more stringent than federal standards, solidification may be unacceptable as a pre-disposal remedy.

Occupational Safety and Health Act

Superfund remedial actions and RCRA corrective actions must be performed in accordance with Occupational Safety and Health Act (OSHA) requirements detailed in 29 CFR Parts 1900 through 1926. State occupational safety and health requirements must also be met and may be more stringent than federal standards.

Section 4
Economic Analysis

One goal of the SITE program is to develop reliable cost data for unique and commercially available hazardous waste treatment technologies. Cost data for the Chemfix technology were obtained primarily from a model provided by Chemfix that is summarized in Table 4-1. Other sources of cost information include EPA experience, the SITE demonstration, and cost information obtained from vendors of equipment related to solidification/stabilization processes. Costs presented in this analysis are order-of-magnitude estimates (-30 to +50 percent).

Site-Specific Factors Affecting Cost

Several factors affecting the cost of the Chemfix system are highly site-specific. They are difficult to calculate without accurate data from a site remedial investigation report. Four sources contribute to the uncertainty and variability of cost estimates for the Chemfix technology: (1) the extent to which the chemical and physical characteristics of the waste match the optimum feed characteristics of the technology, (2) site logistics, (3) waste disposal regulations and requirements, and (4) amount of material on-site.

Basis of Economic Analysis

The cost analysis was based on a standard size Chemfix processing unit capable of treating approximately 160 tons of raw waste per day during an 8 hour day. The cost analysis assumes that the total amount of material treated is 30,000 cubic yards (37,000 tons), which is representative of a typical Superfund site. It is important to note that the cost per ton of treated material will decrease as the total quantity of raw material increases and fixed costs are averaged over more raw waste. During the SITE demonstration, waste material was processed at an average rate of 15 tons per hour, which is significantly lower than the designed rate.

The Chemfix cost model (Table 4-1) was the basis for the economic analysis. Information provided by Chemfix includes a range of expected costs for reagents, labor, miscellaneous operating expenses, and equipment lease as well as an estimate of mobilization and demobilization costs. Cost figures are generally represented in dollars per ton of raw waste. Total cost can be influenced by the rate at which material can be processed because lower processing rates result in higher costs per ton for equipment lease and labor.

Waste Treatment Costs by Category

Costs associated with the Chemfix technology are defined below in 12 cost categories. These categories reflect typical cleanup activities at Superfund and RCRA corrective action sites. This section provides cost information for each category and forms the basis of the cost analysis presented in Table 4-2. Fixed costs refer to costs that are independent of the amount of waste treated. Variable costs are directly dependent on the quantity of waste processed by Chemfix.

Site Preparation Costs

Site preparation costs include those for planning and management, system design, auxiliary and temporary equipment and facilities, legal searches, access rights, preparation of support facilities, minor cleaning of the site, emergency and safety equipment, utility connections, and site support staff. Site preparation costs depend on the type and condition of the site where treatment takes place. The Chemfix cost model estimates $5,000 for site preparation. The range is estimated to be $5,000 to $50,000.

The Chemfix cost model includes costs for many of the activities associated with site preparation and with direct mobilization, use, and demobilization of the Chemfix technology. However, the Chemfix model may underestimate site preparation costs. Considerable costs may be associated with getting a Superfund site ready for a cleanup action, excavating wastes, and clearing the site after the treatment process. Such activities involve setting up decontamination facilities, establishing telephone lines to the site, preparing gravel roads and parking areas, excavating wastes, backfilling the excavation, sample collection, and monitoring health and safety conditions. Many of these activities are labor intensive. A conservative estimate assumes 500 hours of labor at $50 per hour plus costs for utility service hookup and sample collection. Waste excavation costs are excluded in this estimate, but can be estimated at $40 per ton.

Additional materials handling and pretreatment costs must also be considered according to site requirements. Costs for these activities vary significantly depending on the characteristics of the waste being treated. The Chemfix process equipment does not include screening or particle size reduction equipment. This must be rented or purchased in addition to leasing the Chemfix equipment.

Permitting and Regulatory Costs

Permitting and regulatory costs vary depending on whether treatment is performed on a Superfund or a RCRA corrective action site and on how the treated material is disposed of. Section 121(d) of CERCLA as amended by SARA requires that remedial actions be consistent with ARARs for environ-

Table 4-1. Chemfix Cost Model

Category	*Rate*	*EPA Commentary*
Processing Costs		
Labor Cost	*$5 to $15 per ton. Will vary with processing rate and quantity to be processed.*	*Realistic*[a]
Reagent Cost	*$25 to $30 per ton. Will vary with moisture content of waste (moisture or lack of moisture in soil).*	*Realistic*
Miscellaneous operating expenses and maintenance cost (includes health and safety cost)	*$2 to $4 per ton.*	*Realistic*
Equipment Lease[b]	*$3 to $5 per ton. Will vary with processing rate.*	*Slightly low*
Mobilization and Demobilization Costs[c]		
Equipment transfer expenses	*$2.50 per loaded mile per truck (from point of origin and return).*	*Realistic*
Labor costs with expenses	*$380 per day per person.*	*Realistic*
Miscellaneous site expenses	*$100 per day.*	*Very low*
Travel expenses for crew	*$500 per person.*	*Realistic*

[a] *Costs of labor and equipment shown here are realistic for the Chemfix process only. Labor and equipment needed to get the waste to the treatment unit (excavation and materials handling) approximately double the costs shown here.*
[b] *This assumes that Chemfix process equipment is leased for use and does not represent the capital investment required for purchasing the equipment.*
[c] *Mobilization and demobilization costs are one-time costs per job. Equipment transfer expenses vary based on distance from Louisiana to the site.*

mental laws, ordinances, regulations, and statutes. ARARs include federal standards and criteria as well as more stringent standards and criteria promulgated under state or local jurisdictions. Applicable requirements are those for which jurisdictional prerequisites of the underlying statute are satisfied. Relevant and appropriate requirements do not legally apply to the situation or action planned, but are nonetheless suitable because of the characteristics of the remedial action, the pollutants in question, or the physical circumstances at the site. ARARs must be determined on a site-specific basis.

Permitting and regulatory costs are primarily incurred through labor costs; the estimate of $25,000 is based on 250 hours at a labor rate of $100 per hour. Based on the capital equipment total lease cost for 30,000 cubic yards of waste, $25,000 is a reasonable estimate. This estimate does not include relevant permit costs, which may vary significantly depending on state and local requirements. At RCRA corrective action sites, analytical protocols and annual monitoring records must be kept, which increases regulatory costs. For these situations, permitting and regulatory costs would be higher.

Capital Equipment Costs

Chemfix does not sell the patented process equipment used for waste treatment. Moreover, for short-term on-site remediations, it is not economically feasible to make the capital expenditures required to purchase the equipment. Therefore, Chemfix equipment must be rented from Chemfix 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.

Assuming a weekly rate of $5,000, a processing rate of 160 tons per day, and a 7-day work week, the rental/lease cost is approximately $5 per ton of raw waste. The Chemfix cost model gives a range of $3 to $5 per ton. This cost does not include the cost of obtaining pretreatment equipment or waste storage.

Equipment Installation/Startup

Startup costs for the Chemfix process include those required to install the equipment, connect utilities, perform an initial equipment shakedown, and initiate an environmental monitoring program.

In the SITE demonstration of the Chemfix process, mobilization of equipment at the test site took approximately 7 days. Miscellaneous site expenses for mobilization were about $100 per day. Installation of power hookups cost about $2,050. Expenses totaled over $5,500 for other equipment and material used in the startup phase, including 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. Therefore, the total cost of installation and equipment startup was approximately $8,500.

Table 4-2. Estimated Costs of Chemfix Treatment Technology by Category[a]

Fixed Cost Category	Estimated Costs (1990 $)
Site Preparation[b]	*$ 50,000*
Permitting and Regulatory	*$ 25,000*
Equipment Installation and Startup	*$ 8,500*
Trailer Transport to Site	*$ 12,500*
Mobilization/Demobilization	*$ 12,000*
Equipment Repair and Replacement	*NA*[c]
Effluent Treatment and Decontamination	*$ 2,500*
Total Fixed Costs	***$110,500***
Total Fixed Cost per Ton	***$ 3***
Variable Cost Category	Cost Per Ton of Waste Treated
Capital Equipment Rent/Lease[d]	*$ 5*
Labor	*$ 27*[e]
Chemfix Reagents	*$ 30*
Utility and Miscellaneous	*$ 3*
Analytical	*$ 5*[f]
Total Variable Cost per Ton	***$ 70***
Total Treatment Cost per Ton of Raw Waste	***$ 73***[g]

[a] *Based upon 30,000 cubic yards (37,000 tons) processed at 160 tons per day.*
[b] *Excludes excavation costs.*
[c] *Assumed to be included in the cost of renting/leasing equipment from Chemfix.*
[d] *Based on the rent/lease cost of equipment from Chemfix. Does not include costs for purchasing or renting screening devices, size reduction equipment or waste/product storage containers.*
[e] *Includes cost for an operations crew.*
[f] *Excludes the cost of raw waste or site environmental sampling.*
[g] *Excludes the cost of possible post-treatment, curing, storage, excavation, and final disposal.*

Equipment Transport

The Chemfix cost model estimates transportation costs at $2.50 per loaded mile per truck for the round trip between the equipment point of origin (Baton Rouge, Louisiana) and the site. The Chemfix equipment is transported on three to five flat-bed trailers depending on the equipment capacity. The cost analysis assumes a 1,000-mile trip for five Chemfix trailers. Other equipment required for site preparation, processing, and demobilization is assumed to be acquired locally.

Labor Costs

Chemfix estimates that its processing equipment requires a crew of four to five workers. The crew includes four technicians and one senior project engineer working 10-hour shifts at hourly rates of $36.60 and $46.80, respectively. In this scenario, the total daily cost of the crew is approximately $1,900; including fringe and other indirect costs. Assuming expenses of $100 per day per worker, the total labor cost to run the Chemfix process equipment is approximately $2,400 per day.

Assuming that the processing rate is 160 tons per day, the labor cost required for operating the Chemfix technology is $15 per ton of treated material. This is consistent with labor costs in the Chemfix model, which ranges up to $15 per ton, including expenses.

In addition, a support crew is required to transfer excavated soil and deliver it to the Chemfix equipment, to sample soil and treated wastes, to monitor health and safety conditions, and to direct the overall project. The support crew consists of two technicians (a sampling technician and a health and safety officer), two laborers (a backhoe operator and a general crew member), and one resident engineer. Assuming 10-hour shifts and fully loaded hourly rates of $36.60, $31.50, and $46.80 for the technicians, laborers, and engineer, respectively, the total daily labor cost for the support crew is approximately $1,800. At a processing rate of 160 tons per day, this is an additional labor cost of $11.25 per ton of waste treated. Therefore the total labor cost is $26.50 per ton of waste treated.

Supply and Consumable Costs

The principal consumables associated with the Chemfix technology are reagents. The impact of reagent cost on the Chemfix process depends on required reagent concentrations. The exact portions of dry (CHEMSET I-20) and liquid (CHEMSET C-220) reagents in the Chemfix process are proprietary information. Chemfix quotes a reagent cost range of $25 to $35 per ton of material treated. This range is generally consistent with costs associated with alternative reagents that can be used for this type of stabilization/solidification process. For example, treatment reagents similar to those used in the Chemfix process, such as portland cement (30 percent by weight) and sodium silicate (2 percent by weight), yields a cost of $21 per ton of waste treated. Alternative solidification/stabilization processes not using cement, such as pozzolanic processes (for example, those based on the reaction of flyash with lime), have similar reagent costs. Flyash (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 treated waste.

For the cost analysis, supply and consumables cost was assumed to be $30 per ton of treated waste.

Utility and Miscellaneous Costs

The cost of utilities and other miscellaneous operating expenses is estimated from the Chemfix cost model. The estimated cost is $2 to $4 per ton of treated waste; $3 per ton of treated waste was used in the cost analysis.

Effluent Treatment and Decontamination Costs

The Chemfix treatment process has no liquid effluent. Personal protective equipment and monitoring instruments may require decontamination. The cost of treating effluent from decontamination procedures was estimated based on

treating 2,000 gallons of water at $1 per gallon plus $500 in transportation costs.

Analytical Costs

Analytical costs include those for laboratory analyses, data reduction and tabulation, quality assurance/quality control (QA/QC), and reporting. These costs are for verification of treatment effectiveness and do not include waste characterization. Analytical costs will vary according to the types of contaminants and regulatory requirements for the site.

The following assumptions were made for the cost analysis. Analyses are conducted on a percentage of treated waste to verify treatment effectiveness. The analyses include TCLP and UCS tests at an estimated cost of $750 and $50 per sample, respectively. Assuming one sample is collected and analyzed per day, the total cost would be $5,600 for a 7-day work week. This is equivalent to $5 per ton for the assumed processing rate of 160 tons of waste per day.

Equipment Repair and Replacement Costs

Equipment repair and maintenance costs for the Chemfix process are minimal. Chemfix supplies the principal equipment, and repair costs should be covered in the leasing agreement. Some costs may be incurred for maintenance of non-Chemfix equipment such as screens, grinding shredders, or waste storage containers.

Mobilization/Demobilization Costs

Mobilization costs include miscellaneous equipment transfer expenses, labor costs with expenses, miscellaneous site expenses, and travel expenses for the crew. The Chemfix model estimates a minimum of $6,000 for mobilization. Costs for demobilization at the SITE demonstration, including costs for garbage pickup, earth-moving equipment, plant dismantling, and protective clothing for the crew, totaled over $6,000. Therefore, the cost analysis includes $12,000 for mobilization/demobilization costs.

Residuals and Waste Shipping, Handling, and Transportation Costs

The cost of treating wastes with Chemfix technology varies with the disposal method for the treated material. Placement on the original hazardous waste site or disposal in an unlined facility will be less costly than off-site disposal or disposal in a RCRA Subtitle C facility. The cost of on-site disposal in the excavation was approximated at $50 per ton. The costs of residuals disposal in a Subtitle C landfill could exceed $150 per ton.

Potential Additional Costs

Depending on the physical characteristics of the waste and the chemical contaminants, the Chemfix process may not provide a complete, effective remediation unless it is part of a larger treatment train. Various pretreatment operations may be required such as screening large particles, grinding (pulverization), soil washing, or an organics removal technology to separate organic contaminants from the soil. Because waste-specific considerations dictate the necessity of pretreatment operations, they were not considered in the Chemfix cost model. Land disposal of treated waste is another source of additional costs that require consideration. Potential additional costs for solidification/stabilization processes are presented in Table 4-3.

Table 4-3. Potential Additional Costs for Solidification/Stabilization Processes

Options	*Cost (per ton)*
Screening	*$ 3 to 7*
Grinding	*$ 0.5 to 2*
Soil Washing	*$ 100 to 400*
Organics Removal	*$ 250 to 600*
Land Disposal	*$ 50 to 250*

Summary of Economic Analysis

The cost to solidify/stabilize waste material using the Chemfix process is approximately $73 per ton of raw waste. The cost analysis was based on process equipment capable of treating an average of 160 tons per day. This rate is representative of requirements for a soil remediation at a Superfund site.

Estimated treatment cost excludes the cost of waste excavation, environmental site and waste characterization, raw waste pretreatment, and curing, storing and disposal of the treated waste. These costs were excluded because they are either optional items subject to site-specific requirements or are not directly associated with the treatment process. Applications of Chemfix technology should consider these items to develop accurate cost estimates. Cost estimates for land disposal of treated waste range from $50 to $200 per cubic yard.

The largest contributors to total treatment cost are the proprietary reagents and labor. Reagent and labor costs account for 41 and 37 percent of the treatment costs, respectively.

References

American Nuclear Society, 1986, American National Standard Measurement of the Leachability of Solidified Low-Level Radioactive Wastes by a Short-Term Test Procedure, prepared by the American Nuclear Society Standards Committee Working Group, ANS 16.1. ANS, LaGrange Park, Illinois.

American Society of Testing and Materials, 1987, Annual Book of ASTM Standards. ASTM, Philadelphia, Pennsylvania, Volume 4.08, March.

Chemfix Technologies, Inc., 1987, Propose SITE-002 for Development of Innovative Technologies for Hazardous Waste Site Cleanup. Metairie, Louisiana. Prepared for U.S. EPA, HWERL, Cincinnati, Ohio. Chemfix Technologies, Inc.

Hazardous Waste Consultant, Materials that Affect Stabilization/Solidification Processes, pp. 14-16, January/February 1988.

Salas, R.K., 1980, Disposal of Liquid Wastes by Chemical Fixation/Solidification. The Chemfix Process, in Toxic and Hazardous Waste Disposal, Volume One, R. Pojasek, ed. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1980, p. 321-348.

U.S. Environmental Protection Agency, 1979, Methods for the Chemical Analysis of Water and Wastes. U.S. EPA 4-70-020, March.

U.S. Environmental Protection Agency, 1986a, Prohibition on the Placement of Bulk Liquid Hazardous Waste in Landfills, Statutory Interpretive Guidance. EPA 530SW-86-016, June.

U.S. Environmental Protection Agency, 1986b, Test Methods for Evaluating Solid Waste. U.S. EPA Volumes IA and II, Third Edition, U.S. EPA Document Control No. 955-001-00000-1.

U.S. Environmental Protection Agency, 1989, Superfund LDR Guide #1, Overview of RCRA Land Disposal Restriction (LDRs), U.S. EPA Directive 9346.3-01FS.

Appendix A
Key Contacts for the SITE Demonstration

Additional information on the Chemfix technology, the SITE program, and the demonstration site can be obtained from the following sources.

The Chemfix Technology

Philip Baldwin
Chemfix Environmental Services, Inc.
2424 Edenborn Avenue, Suite 230
Metairie, LA 70001
(504) 831-3600

The SITE Program

SITE Project Manager, Chemfix Demonstration

Ed Barth
U.S. Environmental Protection Agency
Office of Research and Development
Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7669

SITE Program, EPA Headquarters

Jim Cummings
U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Office of Policy, Management, and Technology
401 M Street, S.W.
Washington, DC 20460
(202) 382-4362

The Demonstration Site (Portable Equipment Salvage Company, Oregon)

John Sainsbury
U.S. Environmental Protection Agency (HW-093)
1200 Sixth Avenue
Seattle, WA 98101
(206) 442-1196

Appendix B
Vendor's Claims for the Technology

NOTE: This information was provided by CHEMFIX® Technologies, Inc. It has not been edited or changed by EPA.

Process Description of the CHEMFIX® Technology

The CHEMFIX® Process is defined as a chemical fixation/stabilization technology. This patented process, enhanced with proprietary developments, stabilizes mobile constituents of concern within a waste matrix by chemical and physical means.

The CHEMFIX® Process is based on the use of the CHEMSET® C-220 family of poly-silicates and the CHEMSET® family of dry calcium containing dry reagents. This chemistry is assisted as needed by CHEMSET® reaction promoter additives. The combination and proportions of reagents are optimized for each particular waste stream requiring treatment.

The CHEMFIX® inorganic chemical system reacts with polyvalent metal ions, certain other waste components, and also with itself to produce a chemically and physically stable solid material. The cross-linked, three dimension polymeric matrix displays properties of good stability, high melting point and stable, friable soil-like characteristics.

Three classes of interactions can be described within the CHEMFIX® Process. First are the rapid reactions between CHEMSET® poly-silicates, certain reaction promoters and metal ions, producing insoluble metal silicates. Second are reactions between the CHEMSET® C-220 molecules and the reactive components, including calcium oxide within the CHEMSET® dry reagent, producing a gel structure. Third are hydrolysis, hydration and neutralization reactions between the dry reagent and the waste and water (both free and contained).

There are no side streams or discharges resulting from the CHEMFIX® Process. During processing, all the waste is transferred to the process mixer wherein the reagents immediately react to form a gel. This gel is then discharged to the receiving area. The viscosity of the gel varies depending on the total solids of the waste stream prior to processing.

The CHEMFIX® Product (Naturfil) has been demonstrated to exhibit long term stability. Multiple extraction data on new and aged product indicates that the new ionic and covalent bonds formed within the Naturfil matrix are as stable as should be expected from such chemistries.

CHEMFIX® Process Description

The schematic of the CHEMFIX® treatment system is presented in Figure 1. The system consists of a feed hopper, primary conveyor, weigh feeder, high speed shear process mixer (homogenizer), CHEMSET® I-20 dry reagent storage, CHEMSET® C-22 or C-220d (dilute C-220) liquid reagent tank, two alarm and control panels instrumentation, high shear process mixer and other equipment.

A simplified process description can be obtained by tracing the flow of the soil through the treatment system. This system can be divided into two parts: (1) Preparation and (2) Treatment.

The first step in preparation is the transfer of soil from the soil storage area to the soil feed hopper. This hopper has a capacity of 15-20 cubic yards. From the hopper, the soil is then lifted by a primary conveyer to the weigh feeder. The amount of soil to be processed is measured at the weigh feeder. From this, the soil is gravity feed into a high speed shear process mixer (homogenizer) where the water is added. If additional pre-treatment chemicals are required, they would also be blended at this point. A signal representing the weight of the soil to be processed is transmitted to a flow-indicating controller that regulates the flow rates of water to the soil. Water is introduced through a nozzle into the homogenizer to obtain optimum mixing. The ratio of added water to soil can be set at the flow-indicating controller to obtain the homogenizer can be controlled from the alarm and control panel.

The second part of the process, soil treatment, begins as the soil-water mixture is transferred from the homogenizer to the process mixer. The CHEMSET® I-20 and CHEMSET® C-220 are added to the process mixer, which uses a CHEMFIX® designed pug mill to blend all the ingredients. The CHEMSET® I-20 is fed into the process mixer through a dry reagent feeder from the storage silo. The CHEMSET® C-220 is pumped from the liquid reagent storage tank by a positive displacement pump. The proper feed rates for the liquid and dry reagents are regulated at the control panel.

The final NATURFIL® fixed product is discharged from the mixer into a storage bin and transported to the temporary storage area for final curing.

CHEMFIX® Equipment Description

The CHEMFIX® soil treatment system is a self-contained unit mounted on a flat-bed trailer. The system consists of distinct pieces of equipment that, when assembled, are

connected together both physically and electronically. This section discusses each of these distinct pieces of equipment and its function in the processing unit.

Feed Hopper

The feed hopper is where waste material to be treated is introduced, by the front-end loader or other earth-moving equipment, into the treatment system. The CHEMFIX® feed hopper to be used during the SITE demonstration site has an approximate dimension of 9 x 16 feet and a capacity of 15-20 yards per hour.

Primary Conveyor

Waste material from the feed hopper is transferred by conveyor to the weigh feeder.

Weigh Feeder

The weigh feeder receives waste material from the primary conveyor and continually weighs the waste that enters the high speed process mixer. The feeder is electronically connected to the water flow control system and the two CHEMSET® reagent feed systems. Waste is moved through the weigh feeder to the homogenizer. The weight of the soil will regulate the water flow rate to the homogenizer through a flow-indicating controller and a water flow control station.

Water Flow Control System

The water 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.

High Speed Shear Process Mixer

The high speed shear process mixer receives waste material from the weigh feeder and water from the water flow control system. The amount of water that is added is measured by a flow meter and is determined by the amount of waste passing through the weigh feeder.

CHEMSET® Dry Reagent Feeder

The CHEMSET® used in the process is transported to the treatment site and stored in a silo. From the silo it is transferred by an auger to the process mixer. The speed of the auger is controlled in conjunction with the CHEMSET® C-220 or C220d (dilute C-220) by the control panel. The design capacity of the CHEMSET® I-20 feeder is 0-54,000 lbs per hour.

CHEMSET® I-20 Storage Silo

The silo has a capacity of 120,000 lbs and is equipped with a level sensor for high and low levels. When I-20 reaches a low level, an alarm will sound. The silo is also equipped with a baghouse collector. The collector is operated only during the transfer of I-20 from the bulk reagent storage transport vehicle to the silo.

CHEMSET® C-220 Storage Tank

The 10 foot diameter C-220 storage tank, which has a 100,000 lb capacity, is used to hold reagent as needed for the process. The tank is outfitted with a transfer pump and the system may be heated when the temperature is below 45°F.

Liquid Transfer Pump

The pump rate is manually set on the control panel and varies according to the signal received from the weigh feeder.

High Shear Mixer

Wetted waste material from the homogenizer, I-20 silo and C-220 tank are mixed. The waste material is transferred to the process mixer by gravity. The C-220 liquid reagent is pumped to the process mixer and the I-20 dry reagent is transferred to the mixer by an auger. In the mixer, these three ingredients are mixed and then discharged either directly or by a positive displacement or centrifugal pump to the disposal area, waste containers or solidification cells.

Wastes Compatible with the (Stabilization/ Fixation) Technology

1. See the attachment, "Partial List of Wastes Suitable for the CHEMFIX® Treatment."
2. Liquid wastes that contain a minimum of 3%-5% solids are reasonably considered treatable with the Technology for heavy metals fixation/stabilization.
3. Solid wastes are treatable for heavy metals with the Technology either as is or with pre-treatment. Solid wastes should have about 30% moisture available for chemical reaction (this can be added as a part of the reagent additions) and the waste particle size usually needs to be less than 100 mesh prior to reagent addition. Particle size reduction may occur within the Technology mixing equipment or pre-grinding may by required.
4. Volatile organics can only be addressed by the Technology if the level is extremely low, i.e., typically less than 100 ppm. Special CHEMSET® reaction additives are required in these applications.
5. Semivolatile and high molecular weight petrochemicals can be addressed on a case-by-case basis, with or without using CHEMSET® reaction additives. This is an area of new development for the Technology.
6. Heavy metal treatment has been demonstrated possible with the Technology, in the presence of 5%-10% by volume oil and grease.

Favorable Conditions for Execution of the Technology

The outdoor temperature should be above 45 degrees Fahrenheit if the Technology is to be practiced outdoors, or if the curing time is critical and there is no heated space in which the finished product can cure. A stabilized product that would cure substantially within hours at 55-60°F will take 48-60 hours at 45°F and 96+ at 35°F.

Advantages of the Technology

1. The Technology thoroughly treats all of the waste to the same standards, allowing the establishment of a superior Quality Assurance program.
2. Stabilized waste has soil like qualities and can be reused as a soil substitute. This synthetic soil usually has much greater erosion resistance, enhanced slope stability, and can trap soluble heavy metals and sweeten landfill leachate.

3. The Technology produces a synthetic soil that has permeabilities in the soil range, i.e., $1x10^{-5}$ to $1x10^{-7}$ cm/sec range.
4. When amended with some natural soil to assist in moisture retention and nutrient supply, the Technology will produce a synthetic soil that may be used to support vegetation as a topsoil.

Site Application of the Technology

1. Mobile locations where solid or liquid wastes require stabilization and/or fixation are important applications of the Technology.
2. Fixed facilities at a specific generator's plant location are many times economical and convenient for the generator.
3. The Technology can be applied at a Central Treatment Facility where waste are brought from many different generators.

Cost Information on the Technology

1. Mobilization and any required demobilization costs are a function of where the waste site is and what type of waste and quantity is involved. The cost of mobilization/installation could range from as little as less than $10,000 to more than $100,000.
2. CHEMSET® treatment reagent costs will also vary, with wastes with less than 20%-30% moisture being more expensive to treat than liquid wastes. A reasonable range of reagent costs will lie within a $25-$35 per ton spread.
3. Capital budget expenses, based on a 250 ton day year and a five year depreciation schedule (including mobile jobs), should be considered to be in the range of $3-$6 per ton. These numbers may not be valid if the volume processed is small.
4. Miscellaneous operating and maintenance expenses should be budgeted in the $2-$4 per ton range.
5. Labor varies depending on the type and size of operation. A modest to large size job will require 4-5 workers including onsite supervision management.
6. Quality control and quality assurance laboratory work will greatly depend on the job and State requirements. Standard RCRA testing is to be expected, i.e., TCLP or EP leachate testing for metals and potentially some organic components that might be present. The addition of organic testing can substantially increase the cost of any QA/QC program.
7. There are no side streams produced with the Technology. Only wash waters which can be saved and reintroduced into the process for stabilization.
8. Liquid wastes can be treated at the rate of from 200-300 gallons per minute per processing unit. Solid wastes can be treated in the range of from 200-500 cubic yards per day.
9. Finished product disposal varies significantly depending on the project program. The final product could be re-used onsite if the waste has been rendered non-hazardous via "de-characterization" or "delisting." The waste could be re-used as a soil enhancement at a disposal facility.

Mobilization-Demobilization Costs

Project: Treatment of contaminated soils.

Mobilization From: Kenner, Louisiana

Truck trailers typically required: Three

Men typically required: 4 operating technicians, 1 supervisor plus an electrician

Set up time at the site: Typically 1 week

Shakedown period, minimum: 1 week

Equipment transfer expense: $2.50 per loaded mile from Kenner to the site, times three trucks

Example:

Process site distance: 1000 miles

Manpower costs per day with expenses: $380.00 x 6 = $2,280/day x 14 = $31,920.00.

Misc. site expenses: $100/day x 14 = $1,400.00.

Equipment transfer: 3 x 1000 miles x $2.50 = $7,500.00.

Travel expenses for crew: 6 x $500.00 = $3,000.00

Minimum expected mobilization and installation costs = approx. $45,000.00

Demobilization expenses vary depending on distance and the QC cleaning program that is required by the controlling Agency. This total cost could range from 60%-75% of the mobilization costs to as much as the mobilization/installation expenses.

Reagent Costs

A typical soil would be processed at a per ton cost of $25-30. One of the important variables is the moisture or lack of moisture in the soil.

Labor Costs

This includes training required plus periodic medical exams. A typical project will require 4 to 5 personnel with an expected cost of about $5 to $15 per ton, depending on the speed of the processing and size of the job.

Miscellaneous Operating Expenses w/ Maintenance

Budget a typical $2 to $4 per ton.

Capital Equipment Costs

Budget a typical $3 to $6 per ton, depending on the speed of the processing.

Operating Rates

Budget a typical quantity of soil to be processed in a 10 hour work shift at 200-400 tons.

Appendix C
SITE Demonstration Results

The Chemfix solidification/stabilization technology was demonstrated and evaluated under the SITE program at the Portable Equipment Salvage Company (PESC) site in Clackamas County, Oregon, in March 1989. The PESC site was an electrical transformer and metal salvage facility from the 1960s to 1985. Its operations involved scrapping and recycling power transformers containing oils with PCBs. Activities at the site left the soil heavily contaminated with lead, copper, zinc, and PCBs. The objective of the SITE demonstration was to determine the following:

- The ability of the Chemfix process to create a stabilized waste that would meet land disposal restrictions (LDR) requirements for heavy metal wastes (F006) and lead. Specifically, lead concentrations of less than 0.51 mg/L in the TCLP extract and a demonstration-specific soil concentration of 5.0 mg/L were used as benchmarks to evaluate the process.
- The effectiveness of the Chemfix process in reducing the mobility of heavy metals (lead, zinc, and copper) and PCBs. Treatment effectiveness was measured by comparing TCLP test data from before and after solidification/stabilization.
- The ability of the Chemfix process to dechlorinate PCBs.
- The extent to which the Chemfix process alters chemical and physical properties of wastes, and the effect of any alterations on the long-term stability of treated wastes.
- The costs and major cost factors associated with the Chemfix process.

For the SITE demonstration, four on-site locations (Areas A, C, E, and F) were selected for treatment by Chemfix. These locations differed in soil type and contaminant concentration. During the demonstration, Chemfix treated waste from each of the designated areas. Table C-1 summarizes objectives of the demonstration, test methods, and results. A detailed description of demonstration results can be found in the Technology Evaluation Report.

The contaminated waste was extensively sampled and analyzed before and after treatment to determine the effectiveness of the Chemfix process in immobilizing contaminants. Specific analytical procedures used for the demonstration are listed in Table C-2. Analyses conducted on the waste 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. Materials balance data were also collected during the demonstration.

Leaching Tests

The TCLP PCB and metal analyses of the extracts were performed on five duplicate samples of raw and treated soil from each test run to determine percent reductions as a result of treatment. Additional leaching procedures were used to evaluate chemical stability and leaching potential of raw and treated 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 treated waste products.

TCLP

The TCLP is used to evaluate the potential for contaminants to be extracted from waste when codisposed with municipal waste in a landfill. The TCLP is the basis for lead regulations under the LDRs of RCRA. Because the TCLP is a regulatory test for RCRA hazardous wastes, it is a measure of the potential of the Chemfix technology for future applications.

Concentrations of lead, copper, zinc, and other metals in TCLP extracts of treated waste were substantially reduced compared to those of raw waste. PCBs were not found in any TCLP extracts. Table C-3 presents the percent reductions of mean TCLP-extractable lead, copper, and zinc.

The SITE demonstration was designed to test the ability of the Chemfix process to meet potential regulatory standards under RCRA. LDRs are likely to be considered ARARs for Superfund wastes treated by the Chemfix process. However, several land ban standards could also apply to waste treated at this demonstration.

Results of the extraction study were compared to three standards: (1) 0.51 mg/L of lead in the TCLP extract; (2) 99-percent reduction in lead in the TCLP extract following treatment; and (3) 5.0 mg/L of lead in the TCLP extract. The 0.51 mg/L standard is based on the standard for lead in electroplating wastes. The 99-percent reduction standard is discussed in the EPA interim Superfund policy for soil and debris. For wastes with initial concentrations of lead greater than 300 ppm in TCLP extracts, the treatability variance under the LDR requires treatment to achieve 99-percent reduction in lead in the TCLP extracts. The 5.0 mg/L standard is analogous to that used for definition of a characteristic waste (D008). Although the definition of a characteristic waste is based on

Table C-1. 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 0.51 mg/L.*	*70% of samples met the demonstration standard. 65% of samples met the RCRA land ban standard.*
Secondary		
• *Determine the effectiveness of the process in reducing lead, zinc, and copper concentrations in leachates obtained using the TCLP on raw and treated wastes.*	*Compare TCLP lead, zinc, 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.*	*Percent reductions of mean TCLP lead, zinc, and copper concentrations from untreated to treated wastes were 93.5 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 extracts to 1 ppm or less.**	*Compare PCB concentrations in TCLP extracts from treated wastes with those from raw wastes.*	*PCBs were not found in the TCLP extracts 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.*	*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 the stabilization process.*
• *Determine baseline physical properties of 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 Table C-4.*
• *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 Table C-4.*
• *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.*	*Results show that UCS is relatively constant after 14 days. Products showed resistance to freeze/thaw and wet/dry weathering tests.*
• *Determine chemical properties of treated wastes.*	*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.*	*The acid neutralization capacity, electrical conductivity, and pH of the wastes increased dramatically with treatment. Eh was lower after treatment.*

(continued)

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

Table C-1. (Continued)

Objective	*Approach/Method*	*Results*
Secondary (continued)		
• *Determine extraction and leaching properties of treated wastes to indicate their long-term chemical stability.*	*Subject treated wastes to a number of different extraction and leaching tests.*	*Mean lead concentrations in MEP extracts from posttreatment samples generally exceeded the RCRA regulatory level of 5 mg/L for the first extraction. Mean concentrations from the last two extractions showed an upward trend.* *The ANS 16.1 leaching results suggest that diffusion is the controlling mechanism of contaminants from the matrix. The results met the NRC standard for the leachability index. However, 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 treated and raw wastes.*	*These studies are on a scale too small to allow conclusions regarding the product as a whole.*
• *Determine whether significant PCB concentrations are released to the air by the treatment process.*	*Monitor PCB concentrations in the air near the Chemfix equipment during the treatment process.*	*No significant increase in PCB concentration was found during the treatment process.*
• *Determine 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. Use these measurements to calculate dilution factors.*	*Dilution factors for treated wastes varied between 1.33 and 1.40.*
• *Determine effects of aging on the leachability, acid neutralization capacity, and strength of treated wastes.*	*Conduct x-ray diffraction, petrographic, and scanning electron microscopy examinations of treated and raw wastes.*	*No major changes were detected after 6 months.*
• *Determine total cost and major cost factors associated with the process.*	*Evaluate costs of all materials, equipment, and services needed to complete the demonstration.*	*Costs were as follows: $73 per ton of new waste; $50,000 for site preparation exclusive of excavation; plus cost of placement or land disposal.*

Table C-2. Analytical Procedures Used for the SITE Demonstration

Test	*Method*
Leaching Tests	
TCLP	*40 CFR Part 268 (Federal Register, 1986)*
ANS 16.1	*ANS 16.1*
BET	*Modified TMSWC-6 (Côte, 1988)*
MEP	*EPA Method 1320*
Chemical Tests	
pH	*EPA Method 9045/9040*
Eh	*Modified EPA Method 9045*
Electrical Conductivity	*ASA 10-3.3*
Acid Neutralization Capacity	*TMSWC-7*
Total Organic Carbon (TOC)	*ASA 29-3.5.2*
Humic Acid	*ASA 30-3.2*
Oil and Grease	*EPA Method 413.2*
Volatile Organic Compounds (VOCs)	*EPA Method 8240 for VOCs*
Semivolatile Organic Compounds (SVOCs)	*EPA Method 8270 for SVOCs*
Polychlorinated Biphenyls (PCBs) and Pesticides	*EPA Method 8080 for PCBs and Pesticides*
Dioxins and Furans	*EPA Method 8280 for Dioxins and Furans*
Metals	*EPA Methods 6010, 7060, 7421, 7740, 7841, 7470, 7471 for Metals*
Lead Compounds	*WRI Method*[a]
Total Dissolved Solids (TDS)	*EPA Method 160.1*
PCB Dechlorination	*EPA Methods 680 and 3540 and RMC Methods*[b]
Engineering/Geotechnical Tests	
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*

[a]*Lead compounds were determined using the method developed by Western Research Institute.*
[b]*One of the two PCB dechlorination analyses were conducted using procedures developed by RMC Environmental and Analytical Laboratories, Inc.*

Table C-3. Mean Concentrations of Metals in Untreated and Treated Material from SITE Demonstration

	Mean Concentration In Untreated Waste (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*[a]
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*	*93.6*
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*	*93.2*
Area F	*5,100*	*42*	*0.03*	*99.9*

[a] *The effect of dilution from addition of reagents and water was not taken into account.*

results of the extraction procedure (EP) test and not the TCLP, the two extractions are similar for inorganic contaminants in a very alkaline matrix.

Data from TCLP tests were evaluated by comparing individual sample results to the previously described standards. Seventy percent of the TCLP extracts met the 99-percent and 5.0 mg/L standards, and 65 percent met the 0.51 mg/L standard.

American Nuclear Society 16.1 Test

The ANS 16.1 test is used by the nuclear industry to identify mechanisms that control leaching. It indicates the amount of potential leaching from a monolithic solid. This leaching procedure is used to simulate contact of solidified wastes with ground water. Because material is not ground as part of the test as it is in other extraction tests, ANS 16.1 test results provide information on the structural ability of the solidified waste to contain contaminants.

Several facts should be considered in reviewing results of this test. The test is normally conducted on monolith-like solids generated by solidification/stabilization projects in the nuclear power industry. Although the ANS 16.1 test was applicable to the solid produced during the SITE demonstration, the Chemfix process does not always produce a monolithic solid. Therefore, ANS 16.1 test results may have limited applicability to other uses of the Chemfix technology. The ANS 16.1 test was not performed on untreated waste because it was friable soil.

Mean leachate lead concentrations in the ANS 16.1 test extract increased from 0.2 to 2.3 mg/L as the test progressed from an initial contact period of 2 hours to 43 days. Mean leachate copper concentrations per extract increased from 0.05 to 0.28 mg/L over this time. A concurrent increase in mean leachate pH values occurred and ranged from 9.9 to 11.0.

Leachability indices were calculated from results for lead, copper, zinc, and arsenic. The leachability index for lead exceeds the Nuclear Regulatory Commission's leachability index standard of 6 by several orders of magnitude.

Multiple Extraction Procedure

The MEP was performed on raw and treated waste samples from Area C. This procedure was used to determine extraction properties of the waste. The RCRA EP toxicity extraction procedure was used, followed by nine sequential extractions with acidified, distilled water.

The test was included as part of the demonstration because worst-case results of the test have been used in EPA models for delisting RCRA-listed hazardous wastes. The models assume a specific facility scenario and evaluate health effects to a receptor at that facility from exposure to the leachate. Results from EP toxicity extraction can be used to determine whether the waste is a characteristic waste.

Lead, copper, and zinc were found in the first extraction of the MEP as well as in acidified water extractions of raw and treated waste samples. Mean lead concentrations in the original EP toxicity extraction were 663 and 332 mg/L for raw and treated waste, respectively. Mean lead concentrations increased over time in some replicates. This increase suggests that the

treated material may leach as time elapses after disposal if the buffering capacity and structural integrity of the waste matrix decrease.

Interpretation of Leaching Test Results

Extraction test results from TCLP and MEP were evaluated by plotting lead concentrations in the extracts against the final pH of extracts from raw and treated waste samples from all waste collection locations. These relationships are displayed in Figures C-1 and C-2. These figures resemble the normal shape of the solubility curve for lead, with the concentration of lead in the extracts 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. Results of the leaching tests indicate that pH is a major factor controlling leaching from the stabilized and solidified waste.

Chemical Tests

Chemical characteristics determined for the waste include pH, Eh, electrical conductivity (EC), total organic carbon (TOC), acid neutralization capacity (ANC), oil and grease, metals, VOCs, semivolatile organic compounds (SVOCs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), pesticides, PCBs, lead compounds, and humic acid. Table C-4 summarizes results of chemical tests performed on raw and treated soil samples from the PESC site.

The increase in pH (from approximately 7 before treatment to 11 after treatment) is consistent with the alkalinity associated with cementitious additives in Chemfix solidification reagents. Eh is a measure of the reduction/oxidation potential of the material. The decrease in Eh indicates a less oxidizing environment as a result of treatment. The increase in the EC treatment indicates an increase in the number of ions in solution, suggesting that dissolution of the matrix is occurring. This dissolution may be the result of addition of soluble (nontoxic) compounds in the reagent mix or the solubilization of waste components after treatment.

The increase in ANC of posttreatment samples reflects the amount of alkaline reagent added to waste in the treatment process. The metals concentration is represented in Table C-4 by the concentration of lead in the waste. The lead concentration, as well as concentrations of copper and zinc, varied considerably from area to area and within areas. Any apparent decrease in metals concentrations between raw and treated waste samples may be attributed to the variability of the original wastes or to dilution of the material with reagents added during the treatment.

VOCs were not detected in raw waste from Areas A, C, and E. Samples from Area F contained approximately 0.8 mg/kg tetrachloroethylene. This concentration decreased slightly after treatment, presumably because of volatilization during treatment, dilution, or chemical encapsulation. Raw wastes from Areas A, E, and F contained several SVOCs, mostly benzene and pyrene derivatives in concentrations ranging from 2 to 7 mg/kg. The Chemfix process did not reduce SVOC concentrations.

Oil and grease, TOC, PCBs (Arochlor 1016 and 1260), dioxins, and furans were not affected by the Chemfix process.

Physical Tests

Physical tests performed on raw and treated waste included particle size distribution, water content, bulk density, specific gravity, hydraulic conductivity, UCS, immersion UCS, wet/dry weathering, and freeze/thaw weathering. Table C-4 summarizes the results for water content, bulk density, specific gravity, porosity, and hydraulic conductivity. Data from the UCS, immersion UCS, wet/dry weathering, and freeze/thaw weathering tests are discussed below.

Unconfined Compressive Strength

UCS was measured on nine sets of treated samples aged for 14, 21, and 28 days. Each sample set represents the Chemfix product at a specific time during the treatment process and includes three split samples, one for each test time. Samples were cured on-site for 2 days before shipment to the laboratory for analysis. Wet and cold conditions on-site were not ideal for curing.

Results of the UCS test for Area C indicate that the product of the Chemfix process meets the EPA guidance of 50 psi for placement in a landfill. These results also suggest that the UCS value does not change significantly after curing for 14 days. Chemfix staff indicated that solidified/stabilized waste generally sets up in a very short time, within 24 to 72 hours.

Results of UCS tests on samples taken throughout the treatment process show that the UCS of the samples varies considerably from 250 to 130 psi, in the first 2 to 4 minutes of treatment. The UCS decreases to an average of approximately 90 psi after 9 minutes of treatment.

Immersion UCS Test

UCS has two components. Part of the strength of a cured product is the result of particles drying 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 test.

Eighteen treated waste 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. Mean UCS values for each test period were 177 psi for day 30, 188 psi for day 60, and 204 psi for day 90. Results indicate no decrease in strength as the result of increasing periods of immersion. These data suggest that the strength of the solidified product is the result of adhesion between particles of the matrix.

Wet/Dry Weathering Test

Wet/dry weathering tests were performed on molded samples of treated waste from Area C according to method TMSWC-12. Results from these tests are expressed as the cumulative weight loss through 12 wet/dry cycles, normalized to a control sample not subjected to the wet/dry weathering test. Results of tests for all replicates indicate that less than 1 percent of the core weight was lost after 12 wet/dry cycles.

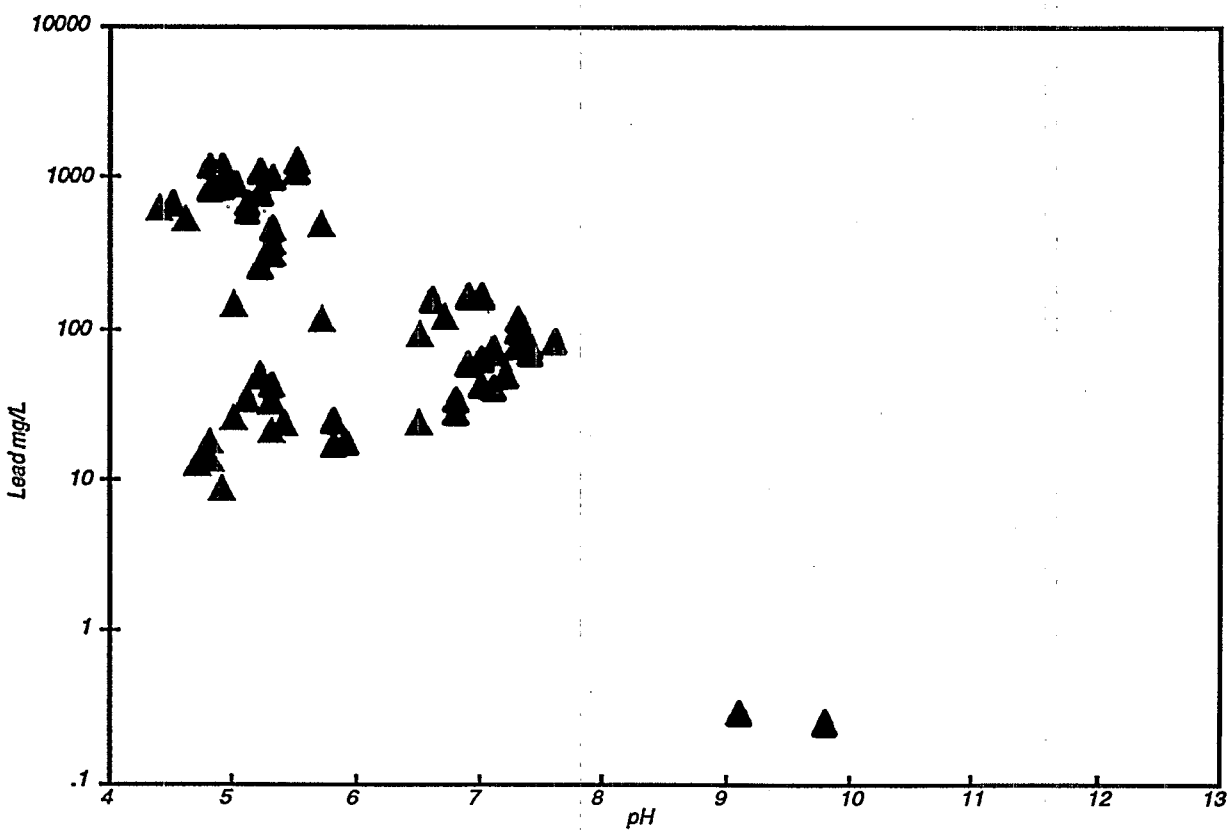

Figure C-1. *Summary of extraction data for raw waste TCLP and MEP data from all areas.*

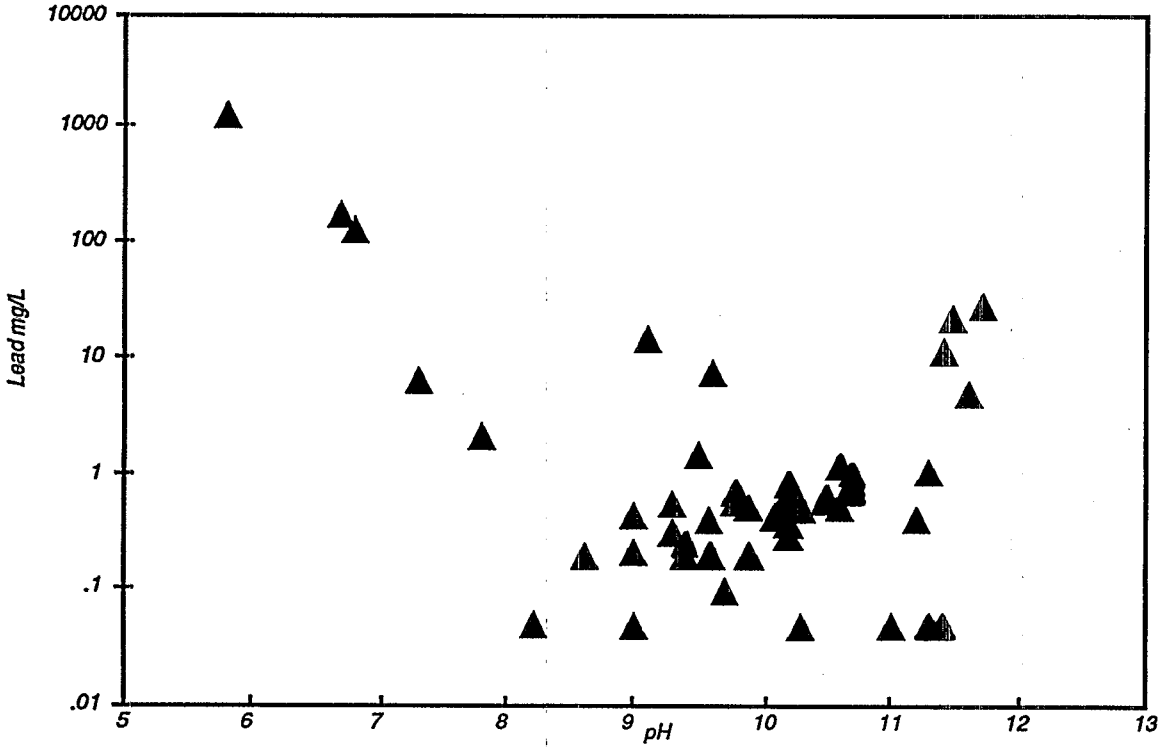

Figure C-2. *Summary of extraction data for treated waste TCLP and MEP data from all areas.*

Table C-4. Chemical and Physical Test Results

	Before Treatment	*After Treatment*
pH (pH units)	*6.5 - 7.5*	*11.0 - 11.8*
Eh (mu)	*140 - 280*	*24 - 53*
Electrical Conductivity (µmhos)	*83 - 340*	*2500 - 4600*
Total Organic Carbon (%)	*3.2 - 7.9*	*3.2 - 7.4*
Acid Neutralization Capacity (meg/g)	*NA**	*2.8 - 4.9*
Oil and Grease (wt %)	*0.4 - 7.5*	*1.4 - 6.5*
Total Lead (mg/kg)	*11,000 - 140,000*	*9,900 - 52,000*
Arochlor 1016 (mg/kg)	*15 - 260*	*13 - 170*
Arochlor 1260 (mg/kg)	*120 - 300*	*95 - 190*
Water Content (wt %)	*12 - 31*	*13 - 19*
Bulk Density (g/cm³)	*1.7 - 2.0*	*1.6 - 2.0*
Specific Gravity	*2.7 - 3.1*	*2.4 - 2.7*
Porosity (%)	*NA*	*32 - 50*
Hydraulic Conductivity (cm/s)	$2.4 \times 10^{-6} - 2.7 \times 10^{-4}$	$3.6 \times 10^{-7} - 1 \times 10^{-6}$

**NA = Not available*

For this test, control samples lost 0.3 to 1.5 percent of their weight.

Freeze/Thaw Weathering Test

Freeze/thaw weathering tests were performed on test cores from molded samples of treated waste from Area C according to method TMSWC-11. Results of these tests were reported in the same manner as those of wet/dry weathering tests. A weight loss of less than 1 percent was found after 12 freeze/thaw cycles. Control samples lost 0.8 to 1.5 percent of their weight. Insignificant weight loss during freeze/thaw weathering tests indicates product durability in an exposed environment.

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, 1987).

The first set of analyses evaluated concentrations of total PCBs and individual PCB congeners in waste before and after treatment. Quantifying concentrations of individual congeners provides information on relative concentrations of congeners with high chlorine content and low chlorine content. An increase in concentration of low-chlorine congeners with a corresponding decrease in concentration of high-chlorine congeners would suggest some dechlorination of the PCB molecule.

Individual PCB homologs (mono through deca) were determined in raw and treated soil samples aged 15, 30, 45, and 60 days. Data showed 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 45 and 60 days contained 68 and 65 mg/kg, respectively. These differences are attributed to sample heterogeneity created by variation in amounts of Chemfix additives in the waste and variation in PCB concentrations in raw waste entering the Chemfix process unit.

Concentrations of PCB homologs (mono through deca) normalized to the hexa homolog revealed elevated concentrations of di, tri, tetra, and penta homologs in treated samples compared to those in raw waste. Marginal decreases were found in hepta and octa homologs, although these differences may not be significant.

In the second set of analyses, treated product was examined for by-products of complete dechlorination of PCBs. These by-products, dihydroxy biphenyls, were not found in any samples of treated waste. A comparison of PCB profiles for raw and treated wastes showed excellent agreement, indicating no chemical change from PCBs to another compound as a result of treatment. The test method was confirmed by spiking a sample of treated waste with dihydroxy biphenyls; 92 percent of the spike was recovered.

Results of these two sets of analyses suggest limited PCB dechlorination. However, it is not known whether this apparent, partial dechlorination is the result of the treatment process or of some other phenomenon such as analytical error, biodegradation, or poor recovery. There was no evidence of products of complete dechlorination. No conclusions can be drawn at this time regarding the effectiveness of the Chemfix process in dechlorinating PCBs.

Air Monitoring

PCB concentration in ambient air close to and downwind of Chemfix equipment was measured with a high-volume air sampling device. Analyses of field and trip blanks and upwind and downwind samples revealed PCB levels equivalent to

concentrations characteristic of an urban environment in the United States (0.7 to 12 ng/m³).

Materials Balance

Table C-5 presents materials balance information for each of the four test runs performed by Chemfix during the demonstration. Approximately 4 to 6 tons of dry soil material were treated for each test run. Dry reagent was added in amounts that varied from 12 to 21 percent of the wet soil material by weight, with an average value of 17 percent. The amount of diluted liquid reagent added was relatively consistent for each test run (20 percent of wet soil weight). Each test run produced approximately 4 to 6 cubic yards of treated material.

Reductions in leachable lead or copper concentrations in treated waste may result from diluting raw waste with reagents used in the treatment process. Therefore, a dilution factor and volume expansion ratio (VER) was calculated for each test run. The dilution factor was 1.3 for Area A and 1.4 for Areas C, E, and F. Contaminated soils from the PESC site were diluted between 30 and 40 percent and were increased in volume between 20 and 50 percent as a result of treatment.

Calculation of the VER requires an estimate of the in situ bulk density of the raw waste; therefore, the VER is relatively site-specific. However, the VER allows users of Chemfix technology to roughly estimate the volume of treated waste that would require disposal based on the quantity of raw waste present at a site.

Table C-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/cm³[d]	1.9	2.0	1.9	1.6	1.7
Total volume, m³[e]	2.9	3.4	4.1	4.5	3.7
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, minutes[f]	20	13	19	16	17
Soil feed, kg/sec	3.5	6.6	5.1	5.7	5.0
Dry reagent, kg/sec	0.44	1.0	0.94	1.2	0.9
Liquid reagent, kg/sec	0.74	1.4	0.89	1.1	1.0
Total feed addition, kg/sec	4.7	9.0	6.9	7.9	6.9

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

Appendix D
Past Applications of the Chemfix Technology

The SITE demonstration provided information on the application of the Chemfix solidification/stabilization process to waste from the PESC site. This appendix summarizes additional applications of the technology to industrial wastes, spiked electroplating wastes, Superfund wastes, and municipal wastes. Information describing these applications was supplied by Chemfix. Quality assurance of the data was not verified.

Industrial Wastes Applications

Chemfix provided information on applications of the solidification/stabilization process to a wide variety of industrial wastes. The Chemfix process was used to solidify/stabilize electroplating wastewater treatment sludge (F006) and dissolved air flotation sludge (K048) to make those wastes eligible for delisting from the EPA list of hazardous wastes noted in 40 CFR 261.31 and 261.32. Electroplating waste spiked with metals and other industrial wastes were also successfully solidified/stabilized.

Chemfix Treatment for Delisting of RCRA Wastes

In September 1985, EPA delisted 150 million gallons of dissolved air flotation sludge (K048) from the Amoco Oil Company after chemical solidification/stabilization of the waste with the Chemfix process. The exclusion required daily testing during the treatment for lead and total chromium in the EP toxicity test extracts to ensure that the process adequately solidified/stabilized the material. In November 1986, EPA delisted approximately 6.8 million gallons of electroplating wastewater treatment sludge (F006) from General Motors Corporation after chemical solidification/stabilization with the Chemfix process. Table D-1 presents a summary of EP toxicity test data for these two delisting projects.

Other Industrial Wastes

The Chemfix process has been used on a wide variety of industrial wastes. Three treatability studies provide examples of the type of experience Chemfix has with industrial wastes:

- Chemfix treated waste stream comprised of arsenic and hydrofluoric acid from production and purification of hydrofluoric acid. Arsenic leached from the raw waste in concentrations greater than 70,000 ppm. After treatment with the Chemfix process, arsenic leached at 2.5 mg/L, and the volume of waste increased by less than 150 percent.
- Chemfix treated electric arc furnace dust (K061) from a U.S. Steel facility. This waste contained metals in the following concentrations:

  3,000 mg/kg total Cr,
  3,000 mg/kg total Cu,
  14,000 mg/kg total Pb,
  70,000 mg/kg total Zn.

  Concentrations of chromium and lead in the treated leachate were less than 0.3 mg/L; data for copper and zinc were not available. Based on results of the treatability study, EPA proposed the waste for delisting from the list of RCRA hazardous wastes.
- The Chemfix process was applied to a mixture of listed waste sludges for which solidification/stabilization was defined as best demonstrated available technology (BDAT). Concentrations of cadmium, nickel, and lead in the TCLP extract from the raw waste were 1.3, 65.8, and 15.6 mg/L, respectively. After Chemfix treatment, concentrations of cadmium, nickel, and lead in the TCLP extract were less than 0.025, 015, and 0.1 mg/L, respectively.

Long-Term Analyses of Treated Industrial Waste

Chemfix supplied data on projects conducted during the 1970s that were reexamined 8 to 12 years after completion. These data provide information on the long-term stability of the Chemfix product (Table D-2).

In 1973, the Chemfix process was used to treat electroplating waste from Ranco, Inc., containing elevated concentrations of cadmium, chromium, and nickel. This waste was sampled in 1985 to determine the long-term stability of the Chemfix product. Concentrations of metals in MEP extracts were all below the limits defining a hazardous waste.

In 1975, the Chemfix process was used to solidify/stabilize refinery wastes from the Sohio Oil Company and the Koch Refining Company. The refinery wastes contained high concentrations of lead and chromium. In 1983, the treated products were sampled to determine leaching characteristics after 8 years of aging. Concentrations of lead and chromium in EP toxicity test extracts were well below levels used to establish a characteristic waste under RCRA.

Small Business Innovative Research Project

In May 1987, Chemfix completed Phase 1 of the Small Business Innovative Research (SBIR) project for EPA. For this study, Chemfix spiked electroplating waste (F006) with a variety of metals and processed the waste with standard

Table D-1. EP Toxicity Test Data for Delisted Wastes Solidified and Stabilized with the Chemfix Process (mg/L)

	Ag	As	Ba	Cd	Cr	Hg	Ni	Pb	Se
1. Amoco Oil (K048) (Pond I)	NA*	0.17	1.4	0.03	0.07	0.05	0.13	1.05	0.15
2. General Motors (F006) (Impoundment #2)	0.034	0.002	0.399	0.019	0.437	<0.001	0.364	0.34	0.002
EP Toxicity Standards	1.0	5.0	100.0	1.0	5.0	0.2	NA	5.0	1.0
Drinking Water Standards	0.01	0.05	1.0	0.01	0.05	0.002	NA	0.05	0.01

** NA = not available.*

Table D-2. EP Toxicity Test Data for Industrial Wastes Solidified and Stabilized with the Chemfix Process during the 1970s (mg/L)

	Ag	As	Ba	Cd	Cr	Hg	Ni	Pb	Se
1. Ranco, Inc.	<0.01	<0.002	<0.1	0.032	0.16	0.018	0.16	0.12	0.016
2. Sohio Oil	NA*	NA	NA	NA	0.182	NA	NA	0.24	NA
3. Koch Refining	NA	NA	NA	NA	NA	0.07	NA	0.32	NA
EP Toxicity Standards	1.0	5.0	100.0	1.0	5.0	0.2	NA	5.0	1.0
Drinking Water Standards	0.01	0.05	1.0	0.01	0.05	0.002	NA	0.05	0.01

** NA = not applicable.*

Chemfix reagents and a variety of additives. The waste was characterized before and after treatment by measuring metal concentrations in TCLP extracts. Although this was a laboratory (bench-scale) study, it is a good supplement to the SITE demonstration because it includes information on metals other than those found at the PESC site in a different waste matrix.

Table D-3 presents results of the SBIR project. Concentrations of cadmium, chromium, copper, zinc, and nickel in TCLP extracts from treated waste were 98 percent less than concentrations in extracts from untreated wastes. The Chemfix process produced a significant (94-percent) reduction in concentrations of lead in TCLP extracts. Mobility of arsenic, barium, selenium, silver, and vanadium was unaffected by the Chemfix process, and mobility of antimony and mercury increased. Reported reductions do not account for dilution of waste by addition of Chemfix reagents. Data were not available on quantities of reagents used and on volume expansion as a result of treatment.

Spiked electroplating waste was also treated with a set of additives to test the effectiveness of the Chemfix process when used in conjunction with other reagents. Table D-4 summarizes results of these tests. The data indicate the following:

- Hexadecyl mercaptan enhanced mercury binding but had little effect on antimony, arsenic, barium, selenium, silver, or vanadium.
- Activated carbon was effective at binding thallium and antimony at concentrations of 100 and 1,000 mg/kg, respectively.
- Polyethylene amine at concentrations of 40,000 mg/kg produced an 80-percent reduction in arsenic in the post-treatment TCLP extract as compared to the pretreatment TCLP extract. However, mobility of copper, thallium, antimony, selenium, and mercury increased.
- Ethylenediamine tetraacetate (EDTA) successfully immobilized arsenic but failed to improve containment of cadmium, lead, copper, thallium, and antimony.

In another part of the SBIR project, municipal waste was spiked with organic pollutants such as pentachlorophenol (PCP), PCBs (Aroclor 1254), and 1-chlorohexodecane. Results indicated a decrease in the concentration of Aroclor 1254 from 1,000 mg/kg on the day of Chemfix treatment to 165 mg/kg after 15 days. The mechanism causing this decrease is unknown.

Superfund Waste Applications

The Chemfix treatment process was tested on two different types of contaminated soil similar to waste found at the PESC site. The first of these tests was conducted on Superfund Analytical Reference Material (SARM), a synthetic waste developed to model a typical Superfund waste. The second test was conducted on soil from an actual Superfund site.

The SARM Test

When Chemfix submitted an application for the SITE program, it treated and analyzed soil produced as SARM. Results of this analysis are presented in Table D-5. These results confirm SBIR project results for cadmium, copper, chromium, nickel, lead, and zinc. Concentrations of these metals in TCLP extracts were reduced 99 percent by Chemfix treatment.

The concentration of arsenic in the TCLP extract from the treated material was 97 percent less than that from the untreated material. This is a significant difference from the result of the SBIR study in which arsenic in the TCLP extract was reduced only 22 percent. According to these tests and other treatability studies, the ability of the Chemfix process to immobilize arsenic varies with the matrix being treated.

Table D-3. Application of Standard Chemfix Treatment Technology to Waste Spiked with Inorganic Contaminants

Metals	Concentrations of Spiked Sludge in TCLP Extract (mg/L)	Concentrations of Chemfix Product in TCLP Extract (mg/L)	Percent Reduction[a] by Chemfix Process
Cadmium	34.8	0.072	99.8
Lead	3.97	0.24	94.0
Copper	23.5	0.43	98.2
Thallium	13.5	12.4	8.2
Antimony	0.50	2.84	No Reduction[b]
Arsenic	1.57	1.23	21.7
Selenium	0.020	0.054	No Reduction[b]
Silver	0.01	0.01	No Reductionb
Vanadium	<0.1	0.5	No Reduction[b]
Zinc	158	0.265	99.8
Barium	0.8	1.1	No Reduction[b]
Chromium	7.1	<0.05	>99.9
Mercury	2.07	2.12	No Reduction[b]
Nickel	31.9	0.18	99.4

[a] *These percent reductions do not account for dilution of waste by addition of reagents. No information is available on the quantity of reagents used.*

[b] *TCLP metal leachate from the Chemfix product was higher than leachate from spiked sludge.*

Source: Chemfix, 1987, Demonstration of Innovative Technologies for Hazardous Waste Site Cleanup. Response to Proposal SITE - 002.

Table D-4. Application of Chemfix Treatment Technology with Assorted Additives to Spiked Electroplating Waste

Metals	Concentrations of Spiked Sludge in TCLP Extract (mg/L)	Concentrations of Chemfix Product in TCLP Extract (mg/L)	Concentrations in TCLP Extract after Application of Chemfix Process with These Additives			
			Hexadecyl Mercaptan @ 4,000 mg/L	Activated Carbon @ 1,000 mg/L	Polyethylene Imine @ 40,000 mg/L	Ethylenediamine Tetraacetate @ 100 mg/L
Cadmium	34.8	0.072	0.073	0.043	0.08	0.36
Lead	3.97	0.24	0.2	0.35	0.3	0.3
Copper	23.5	0.43	0.18	0.40	1.22	0.66
Thallium	13.5	12.4	7.5	0.32	15.8	12.4
Antimony	0.50	2.84	1.43	0.49	2.81	4.0
Arsenic	1.57	1.23	1.68		0.33	0.067
Selenium	0.020	0.054	0.41		0.71	
Silver	0.01	0.01	0.7		0.03	
Vanadium	<0.1	0.5	0.5		—	
Zinc	158	0.265	0.052		0.082	
Barium	0.8	1.1	0.9		1.4	
Chromium	7.1	<0.05	<0.05		—	
Mercury	2.07	2.12	0.0015		6.9	
Nickel	31.9	0.18	0.19		0.24	

Source: Chemfix, 1987, Demonstration of Innovative Technologies for Hazardous Waste Site Cleanup. Response to Proposal Site - 002.

Treatability Study for Superfund Soil

The Chemfix stabilization process was used to treat soil from a Superfund site in the northeastern United States. Metals in the soil included arsenic, cadmium, chromium, copper, lead, nickel, and zinc. Table D-6 shows metals concentrations in TCLP extracts from soil before and after treatment. The Chemfix stabilization process reduced these metals concentrations by 97 to 99 percent. The total reagent addition was less than 25 percent of the waste by weight.

Municipal Sludge Applications

The Chemfix process was successfully used to stabilize sewage sludge from the South Essex Sewerage District that contained high levels of animal fats and metals. The treated sludge was used as daily cover and final capping material for sanitary landfills. From 1981 to 1984, the Chemfix treatment process was used to stabilize 600 tons per day of municipal sewage sludge from the Blue Plains Wastewater Treatment Plant. A total of 240,000 tons of solidified/stabilized product was used as supplemental capping material for Maryland sanitary landfills.

The Chemfix process was used to treat approximately 100 tons per day of dewatered sludge from the Gloucester County Utilities Authority. The treated sludge was used as intermediate and final cover for a municipal sanitary landfill. Table D-7 shows data from these three applications of the Chemfix technology. No information on untreated sludge is available.

Table D-5. Results of Application of Chemfix Process to SARM

Metals	*Concentration in TCLP Extract From Untreated Material*		*Concentration in TCLP Extract From Treated Material*		*Mean Percent Reduction**
	Sample 1 (mg/L)	*Sample 2 (mg/L)*	*Sample 1 (mg/L)*	*Sample 2 (mg/L)*	
Arsenic	*10.5*	*10*	*0.384*	*0.176*	*97*
Cadmium	*28*	*27*	*<0.005*	*<0.005*	*99*
Chromium	*7*	*8*	*0.10*	*0.10*	*99*
Copper	*175.5*	*209.5*	*0.12*	*0.12*	*99*
Nickel	*21.5*	*21*	*0.23*	*0.23*	*99*
Lead	*38*	*28*	*<0.05*	*<0.05*	*99*
Zinc	*530*	*520*	*0.033*	*0.53*	*99*

** These percent reductions do not account for dilution of waste by addition of reagents. No information is available on the quantity of reagents used.*

Table D-6. Summary of Results from Treatability Study Involving Contaminated Soil from Superfund Site

Metals	*Concentrations in the Extract (mg/L)*	
	Before Treatment	*After Treatment*
As	*10.5*	*0.29*
Cd	*28.0*	*0.28*
Cr	*7.0*	*0.07*
Cu	*176.0*	*1.76*
Pb	*38.0*	*0.38*
Ni	*21.5*	*0.21*
Zn	*530.0*	*5.3*

Table D-7. EP Toxicity Test Data from Municipal Wastes Stabilized with the Chemfix Process (mg/L)

	Ag	*As*	*Ba*	*Cd*	*Cr*	*Hg*	*Ni*	*Pb*	*Se*
1. South Essex Sewerage District	*NA**	*0.02*	*0.31*	*0.03*	*0.12*	*0.003*	*0.18*	*0.32*	*0.01*
2. Blue Plains Wastewater Treatment Plant	*NA*	*<0.002*	*0.6*	*<0.001*	*0.013*	*<0.0005*	*NA*	*0.005*	*NA*
3. Gloucester County Utilities Authority	*0.01*	*0.005*	*0.2*	*<0.005*	*0.08*	*0.0009*	*NA*	*<0.05*	*0.003*
EP Toxicity Standards	*1.0*	*5.0*	*100.0*	*1.0*	*5.0*	*0.2*	*NA*	*5.0*	*1.0*
Drinking Water Standards	*0.01*	*0.05*	*1.0*	*0.01*	*0.05*	*0.002*	*NA*	*0.05*	*0.01*

** NA = not available.*

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