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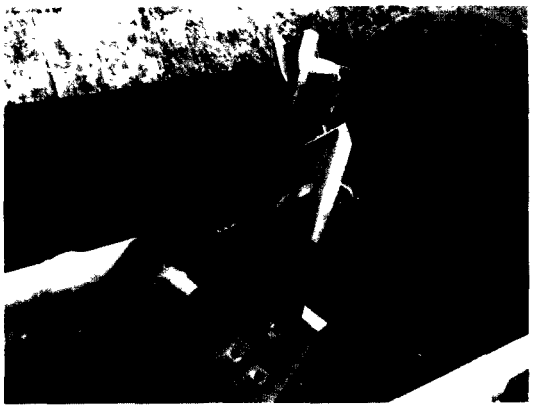
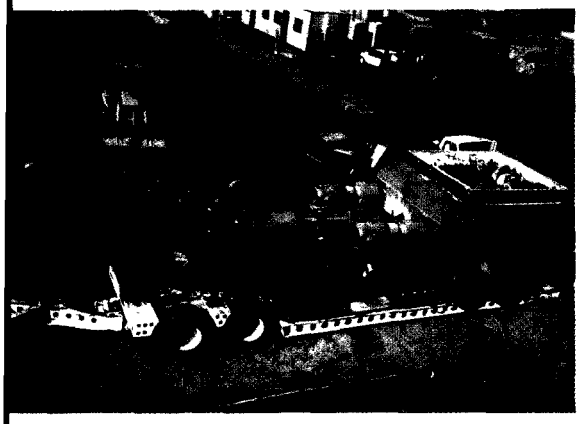
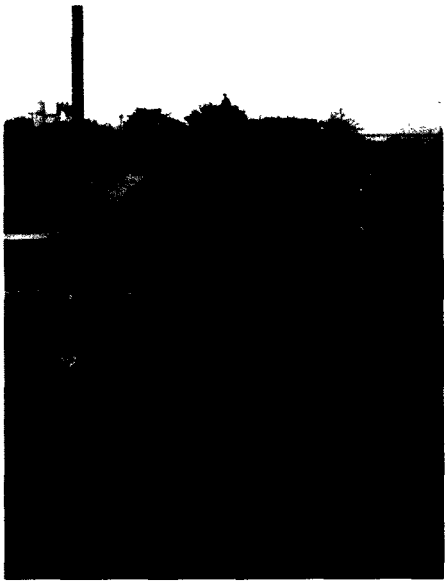
Silicate Technology Corporation's Solidification/ Stabilization Technology for Organic and Inorganic Contaminants in Soils

Applications Analysis Report



SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/AR-92/010
December 1992

OLS # 1970

SILICATE TECHNOLOGY CORPORATION'S SOLIDIFICATION/STABILIZATION TECHNOLOGY FOR ORGANIC AND INORGANIC CONTAMINANTS IN SOILS

APPLICATIONS ANALYSIS REPORT

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Foreword

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

This project was a field demonstration under the SITE program and was designed to analyze the Silicate Technology Corporation solidification/stabilization technology. The technology demonstration took place at a lumber treating facility in Selma, California. The demonstration effort was directed to obtain information on the performance and cost of the technology and to assess its use at this and other uncontrolled hazardous waste sites. Documentation consists of two reports: (1) a Technology Evaluation Report that describes the field activities and laboratory results; and (2) this Applications Analysis Report that provides an interpretation of 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 Martin Luther King Drive, Cincinnati, Ohio 45268. Requests should include the EPA document number found on the report's cover. When this limited supply is exhausted, additional copies can be purchased from the National Technical Information Service, Springfield, Virginia 22161, (703) 487-4650. Reference copies will be available at EPA libraries in the Hazardous Waste Collection.

E. Timothy Oppelt, Director

Risk Reduction Engineering Laboratory

Abstract

This Applications Analysis Report evaluates the solidification/stabilization treatment process of Silicate Technology Corporation (STC) for the on-site treatment of hazardous waste. The STC immobilization technology utilizes a proprietary product (FMS Silicate) to chemically stabilize and microencapsulate both organic and inorganic wastes, and to physically solidify contaminated soils.

The STC treatment technology demonstration was conducted under EPA's Superfund Innovative Technology Evaluation (SITE) Program in November, 1990, at the Selma Pressure Treating (SPT) wood preserving site in Selma, California. The SPT site was contaminated with both organics, predominantly pentachlorophenol (PCP), and inorganics, mainly arsenic, chromium, and copper. Extensive sampling and analyses were performed on the waste both before and after treatment to compare physical, chemical, and leaching characteristics of raw and treated wastes. STC's contaminated soil treatment process was evaluated based on contaminant mobility, measured by numerous leaching tests; structural integrity of the solidified material, measured by physical and engineering tests and morphological examinations; and economic analysis, using cost information supplied by STC and supplemented by information generated during the demonstration. This report summarizes the results of the SITE demonstration, the vendor's design and test data, and other laboratory and field applications of the technology. It discusses the advantages, disadvantages, and limitations, as well as estimated costs of the technology.

Conclusions resulting from this SITE demonstration evaluation are that (1) the STC process chemically stabilized contaminated soils containing both inorganic and semivolatile organic contaminants; (2) PCP concentrations were reduced by 91 to 97 percent as determined by total waste analysis (SW-846, Method 8270); (3) arsenic and copper were immobilized based on various leach-test criteria; (4) chromium concentrations were very low prior to and after treatment, but showed a slight to moderate increase in leachability after treatment; (5) PCP concentrations remained above California state regulatory threshold levels after treatment, and metal contamination in the treated waste did not consistently meet California state regulatory thresholds; (6) the short-term physical stability of the treated waste was good, with unconfined compressive strengths well above landfill solidification recommendations; (7) due to the addition of reagents, treatment resulted in a volume increase of 59 to 75 percent (68 percent average) and a slight bulk density increase; (8) six-month monitoring showed increased concentrations of the contaminants released from the treated waste; (9) eighteen-month monitoring showed improved percent reductions for arsenic and PCP relative to the 6-month cured sample

Abstract (Continued)

test results; chromium and copper showed slight to moderate increases in leachate concentrations over time; and unconfined compressive strengths increased an average of 71 percent relative to the 28-day values; (10) the reagent cost to treat a cubic yard of contaminated waste using STC's technology is estimated to range from $80 to $153 depending on the initial organic content of the waste; and (11) treatment processing costs are expected to range from $40 to $175 per cubic yard when used to treat 15,000 cubic yards of waste similar to that found at the STC demonstration site.

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Abbreviations

AAR	Applications Analysis Report
ACI	American Concrete Institute
AEA	Atomic Energy Act
amp	ampere
ANS	American Nuclear Society
ARAR	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
CAA	Clean Air Act
CEPA	California Environmental Protection Agency
CALWET	California Waste Extraction Test
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm	centimeter
CRWQCB	California Regional Water Quality Control Board
CWA	Clean Water Act
°C	degree Celsius
DL	Detection Limits
DOE	Department of Energy
DOT	Department of Transportation
EDX	Energy Dispersive X-ray
Eh	Oxidation/Reduction Potential
EP	Extraction Procedure
EPA	Environmental Protection Agency
ESBL	Engineering-Science, Inc. Berkeley Laboratory
FIT	Field Investigation Team
FRTL	Federal Regulatory Threshold Limit
ft	feet
FTIR	Fourier Transform Infrared Spectroscopy
g	gram
gal	gallon
HCP	Hazard Communication Program
HDPE	High-Density Polyethylene
hp	horsepower
hr	hour
HRS	Hazard Ranking System
HSL	Hazardous Substance List
HSWA	Hazardous and Solid Waste Amendments
kg	kilogram
L	liter
lbs	pounds
LDR	Land Disposal Restrictions
LI	Leachability Index
meq	milliequivalents
mg	milligram
mo	month
mm	millimeter

Abbreviations (Continued)

MSDS	Material Safety Data Sheets
mV	millivolts
NA	Not Analyzed
NAPL	Non-Aqueous Phase Liquid
NC	Not Calculable
ND	Not Detected
NIOSH	National Institute for Occupational Safety and Health
NPDES	National Pollutant Discharge Elimination System
NPL	National Priority List
NRC	Nuclear Regulatory Commission
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PCDD	Polychlorinated Dibenzo-p-Dioxin
PCDF	Polychlorinated Dibenzofuran
PCP	Pentachlorophenol
POTW	Publicly Owned Treatment Works
PPE	Personal Protective Equipment
ppb	parts per billion
ppm	parts per million
psi	pounds per square inch
QA/QC	Quality Assurance/Quality Control
QAPjP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RFP	Request For Proposal
RI/FS	Remedial Investigation/Feasibility Study
RM	Reagent Mixture
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
sec	second
SEM	Scanning Electron Microscopy
SI	International System of Units
SITE	Superfund Innovative Technology Evaluation
SPT	Selma Pressure Treating
STC	Silicate Technology Corporation
STLC	Solubility Threshold Limit Concentration
TCLP	Toxicity Characteristic Leaching Procedure
TCP	Tetrachlorophenol
TER	Technology Evaluation Report
TMSWC	Test Methods for Solidified Waste Characterization
TPH	Total Petroleum Hydrocarbons
TSCA	Toxic Substances Control Act
TSDF	Treatment, Storage, and Disposal Facility
TTLC	Total Threshold Limit Concentration

Abbreviations (Continued)

TWA	Total Waste Analysis
UCS	Unconfined Compressive Strength
UIC	Underground Injection Control
VOC	Volatile Organic Compound
wk	week
yd	yard
yr	year
XRD	X-ray Diffraction

Conversion of U.S. Customary Units to SI Units

Length

inches	x	25.4	=	millimeters
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

Mass

pounds	x	0.4536	=	kilograms
short tons	x	0.9072	=	metric tons

Temperature

5/9	x	(° Fahrenheit - 32)	=	° Celsius

Note:

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

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Section 1.0

Executive Summary

1.1 Introduction

The Silicate Technology Corporation (STC) immobilization technology is a solidification/stabilization treatment process that was evaluated under the Superfund Innovative Technology Evaluation (SITE) program of the U.S. Environmental Protection Agency (EPA). This immobilization technology is designed to treat organic and inorganic contaminants and thereby reduce the mobility and leaching potential of these constituents in contaminated soils and sludges. For purposes of this report, "solidification" refers to the physical consolidation of contaminated soil into a hard, rock-like material. "Stabilization" refers to the chemical immobilization of hazardous contaminants. STC's proprietary silicate-mineral reagents bind the contaminants within a layered alumino-silicate structure prior to encapsulating the waste in a concrete-like material, thus producing a high-strength, leach-resistant monolith.

The STC technology demonstration was performed at the Selma Pressure Treating (SPT) site in Selma, California during November, 1990. In general, the STC technology demonstration had the following four objectives:

- Assess the technology's ability to stabilize organic and inorganic contaminants.
- Assess the structural characteristics of the solidified waste and the effectiveness of stabilization over a 3-year period.
- Determine volume and density increases resulting from the treatment process.
- Develop information required to estimate the capital and operating costs for the treatment system.

The purpose of this report is to present information from the SITE demonstration and additional case studies that is useful for assessing the applicability of the STC immobilization technology at Superfund, Resource Conservation and Recovery Act (RCRA), and uncontrolled hazardous waste sites. Section 2 presents an overview of the SITE program, a description of the STC technology, and a list of contacts for the technology demonstration. Section 3 discusses information relevant to the technology's application, such as site characteristics, operating and maintenance requirements, potential community exposures, and potentially applicable environmental regulations. Section 4 summarizes the costs associated with implementing the technology. Appendices A through C include the following: the vendor's claims regarding the treatment of organic and inorganic hazardous wastes, sludges, and contaminated soil material; a summary of the results from the SITE demonstration; and five summaries of case studies.

1.2 Overview of the SITE Demonstration

The SPT site was selected to evaluate the effectiveness of STC's immobilization technology for soils contaminated with both organic and inorganic constituents. The waste material was reported to contain pentachlorophenol (PCP; 1,900 to 8,400 parts per million (ppm)), arsenic (375 to 1,900 ppm), chromium (1,900 ppm), and copper (1,500 ppm). In addition, oil and grease levels ranged from 10,000 to 20,000 ppm. Prior to treatment, soil pH was slightly acidic to neutral and moisture content ranged from 4 to 6 percent (CDM, 1989 and U.S. EPA, 1990a).

During the SITE demonstration, approximately 16 tons of contaminated soil material were treated. STC's proprietary alumino-silicate compounds were added to the waste to chemically fix, and thereby stabilize heavy metals and semivolatile organic constituents. Addition of a silicate solidifying agent microencapsulates the adsorbed contaminants, thereby producing an additional physical barrier to leaching.

The STC technology demonstration required 6 days to complete once all of the treatment equipment was set up. Initial processing consisted of treating a clean sand with a mixture of STC's proprietary SOILSORB reagents (P-4 and P-27). On each of the following 5 days, one 2.5-cubic-yard batch of contaminated soil was treated. Surface "hardpan" and sand from an unlined, dry waste disposal pond was collected to a depth of 2 to 3 feet and thoroughly mixed prior to the addition of the STC reagents and water. The surface "hardpan" consisted of PCP-soaked and encrusted sand resulting from 40 years of wood treating operations. Significant inhomogeneity in the treated waste from Batch 2 resulted in pretreatment screening of the remaining batches (3 through 5) and led to the exclusion of Batch 2 from further analysis.

Samples of raw and treated waste were submitted for chemical and physical characterization. Analytical testing was targeted towards selected inorganic constituents (arsenic, chromium, and copper) and organic contaminants (primarily PCP), using various leach tests plus total waste analysis (TWA) extraction procedures. EPA SW-846 Methods 8240 and 8270 were used for TWA of volatile and semivolatile organic compounds, respectively. TWA for metals was performed on acid extracts using EPA SW-846 Methods 3010, 3020, 3050, 6010, 7060, 7421, 7740, 7841, 7471, and 7470 (U.S. EPA, 1986b). Leach tests included the EPA SW-846 Method 1311 Toxicity Characteristic Leaching Procedure (TCLP), modified TCLP-Distilled Water and TCLP-Cage tests, the California Waste Extraction Test (CALWET) as described in the California Health and Safety Code, Section 66700, and a modified version of the American Nuclear Society (ANS) 16.1 (ANS, 1986). Additional chemical and physical characterization of the raw and/or treated waste included pH, Eh, loss on ignition, neutralization potential, particle size analysis, bulk density, permeability, unconfined compressive strength, wet/dry and freeze/thaw analyses, petrographic examination, X-ray diffraction, scanning electron microscopy, and Fourier transform infrared spectroscopy (U.S. EPA, 1990b).

1.3 Conclusions from the SITE Demonstration

To constitute treatment under Superfund, immobilization (i.e., solidification/stabilization) technologies must chemically limit the mobility of the contaminants. Specifically, before a technology can be selected as a treatment alternative, EPA guidance suggests that an immobilization technology demonstrates a significant reduction (i.e., a 90 to 99 percent reduction) in the mobility of chemical constituents of concern (OSWER Directive No. 9200.5-220). The reduction in mobility is evaluated using the TCLP for inorganics and TWA for semivolatile organics. In addition, federal and state regulatory thresholds must be met to allow for legal disposal as nonhazardous wastes either on site or in landfills. The following conclusions about the effectiveness and cost of STC's solidification/stabilization treatment process are based on results of analytical data and general observations from this SITE demonstration as discussed in Section 4 and Appendix B of this report.

PCP (Targeted for treatment):

- TWA extract concentrations of PCP were reduced 91 to 97 percent.
- TWA extract concentrations of PCP were well above the California state regulatory threshold level of 17 ppm for total waste prior to and after treatment.
- TCLP leachate concentrations of PCP varied from negative percent reductions to greater than 81 percent reduction.
- TCLP-Distilled Water leachate concentrations of PCP were reduced 80 to 97 percent.
- PCP concentrations were well below the federal regulatory threshold TCLP level of 100 ppm prior to and after treatment.

- CALWET leachate concentrations of PCP were above California's solubility threshold level of 1.7 ppm prior to and after treatment.

- Stabilization of semivolatile organic compounds (exclusive of PCP) and volatile organic compounds could not be evaluated due to the low concentrations of these analytes in the raw waste.

Arsenic (Targeted for treatment):

- TCLP leachate concentrations of arsenic were reduced 35 to 92 percent.

- TCLP-Distilled Water leachate concentrations of arsenic were reduced 98 percent or more.

- Arsenic concentrations were below the federal regulatory threshold TCLP level of 5.0 ppm prior to and after treatment.

- CALWET leachate concentrations of arsenic were both above and below California's solubility threshold level of 5.0 ppm after treatment.

- TWA extract concentrations of arsenic were both above and below the California state regulatory threshold level of 500 ppm for total waste prior to and after treatment.

Chromium (Not targeted for treatment):

- TCLP leachate concentrations of chromium were increased as a result of treatment.

- TCLP-Distilled Water leachate concentrations of chromium varied from -42 to 54 percent reduction.

- Chromium concentrations were below the federal regulatory threshold TCLP level of 5.0 ppm prior to and after treatment.

- CALWET leachate concentrations of chromium were well below California's solubility threshold level of 560 ppm prior to and after treatment.

- TWA extract concentrations of chromium were below the California state regulatory threshold level of 2,500 ppm for total waste prior to and after treatment.

Copper (Not targeted for treatment):

- TCLP leachate concentrations of copper were reduced 90 to 99 percent.

- TCLP-Distilled Water leachate concentrations of copper were reduced 86 to 90 percent.

- CALWET leachate concentrations of copper were both above and below California's solubility threshold level of 25 ppm prior to and after treatment.

- TWA extract concentrations of copper were below the California state regulatory threshold level of 2,500 ppm for total waste prior to and after treatment.

Long-Term Results:

- TCLP-extracts for metals and TWA for PCP of the 6-month cured samples showed increased concentrations of contaminants released from the treated waste.

- Analyses for the 18-month cured samples showed improved percent reductions relative to the 6-month cured sample test results for arsenic, averaging 88 percent reduction, and PCP averaging 96 percent reduction. Chromium and copper concentrations showed slight to moderate increases in the TCLP-extracts over time.

Physical Properties:

- Unconfined compressive strength (UCS) of the treated wastes was moderately high, averaging 260 to

350 pounds per square inch (psi). Eighteen-month UCS tests show an average 71 percent increase in physical strength with time, averaging 760 to 1,400 psi.

- The relative cumulative weight loss after 12 wet/dry and 12 freeze/thaw cycles was negligible (less than 1 percent).

- Permeability of the treated waste was low (less than 1.7×10^{-7} cm/sec).

- Due to the addition of reagents, treatment of the wastes resulted in volume increases ranging from 59 to 75 percent (68 percent average), with slight increases in bulk density.

- Petrographic and scanning electron microscopy examinations indicate good binder-to-aggregate bonding. Constituents comprising the reagent mix binder included calcium hydroxide, glass, portland cement, and black pigment. Soil constituents were predominantly quartz and feldspar with minor hornblende and trace mica.

Treatment Technology:

- No equipment-related problems occurred during the 6-day technology demonstration.

- The process equipment used during the demonstration was capable of mixing all components, including the waste material, into a homogeneous, solidified product, provided that pretreatment screening or size reduction of surface hardpan material down to 0.04 - 0.08 inch (1-2 mm) was conducted.

Unit Costs:

- The STC treatment process is expected to cost approximately $190 to $330 per cubic yard when used to treat large amounts (15,000 cubic yards) of waste similar to that found at the STC demonstration site.

- Reagent costs are estimated to range from $80 to $153 per cubic yard depending on initial total organic content of the waste.

- Processing costs are estimated to range from approximately $40 to $175 per cubic yard of waste.

1.4 Results From the Case Studies

Information on the STC immobilization technology's performance at the following five facilities was evaluated to provide additional performance data:

1. Tacoma Tar Pits, Tacoma, Washington
2. Purity Oil Sales Site, Fresno, California
3. Kaiser Steel Corporation, Fontana, California
4. Brown Battery Breaking Superfund Site, Reading, Pennsylvania
5. Lion Oil Refinery, El Dorado, Arkansas

Results from the five case studies, summarized in Appendix C, suggest that the STC solidification/stabilization treatment process is capable of chemically stabilizing selected inorganic and organic contaminants from waste material ranging in consistency from soils to sludges. Limited solidification test data also suggest that the technology is able to produce a solidified monolith from contaminated sludges as well as soils. Much of the information obtained from these case studies pertains to chemical analyses from preliminary treatability studies performed at the above sites. The first three case studies were conducted under the SITE program as preliminary investigations to the STC SITE demonstration. The various chemical and leach tests used to evaluate STC's technology performance at the individual sites include TCLP, TWA, EP Toxicity, ANS 16.1, and CALWET.

1.5 Waste Applicability

The STC solidification/stabilization treatment process can be applied to contaminated soils containing both inorganic and semivolatile organic constituents as shown by this SITE demonstration and several case studies. Treatability testing is necessary to determine the amount of reagents necessary for adequate solidification/stabilization according to

variations in organic and inorganic contaminant concentrations. In addition, STC reports that its technology can also remove organics from ground water and chemically stabilize both organics and inorganics in hazardous waste sludges. Potential sites for applying this technology to contaminated soils and sludges include Superfund and RCRA corrective action sites where semi- or nonvolatile organics or inorganics, or a combination of the contaminants exists. STC indicates that this treatment process is not recommended for wastewater contaminated with low-molecular-weight organic contaminants such as alcohols, ketones, and glycols.

1.6 Economic Analysis

Major factors and assumptions in evaluating the cost of the STC technology include: (1) waste volume and site size; (2) technology design and performance factors; (3) technology operating requirements; (4) utilization rates and maintenance schedules; (5) variability in waste type and site conditions; and (6) financial factors, such as depreciation, interest rates, and utility costs.

Itemized treatment costs for the STC technology include: (1) site preparation costs; (2) equipment costs, including both major equipment costs and auxiliary equipment costs; (3) startup costs; (4) supplies and consumables; (5) labor; (6) utilities; (7) analytical costs; (8) maintenance costs; and (9) site demobilization costs. The total treatment cost for the STC technology for remediating 15,000 cubic yards of waste contaminated with similar constituents as those found at the SPT site was estimated to range from $2,843,534 to $4,913,308 depending on mixer size and duration of mixing. This cost equates to approximately $190 to $330 per cubic yard of raw waste; supplies, labor, and analytical expenses account for the largest portions of the total treatment cost. Contaminated soil at sites containing negligible concentrations of organics could be treated at an estimated cost as low as $120 to $255 per cubic yard of raw waste. The reagent cost to treat a cubic yard of waste ranged from $80 to $153 depending on the initial total organic content of the soil. Processing costs ranged from approximately $40 to $175 per cubic yard of waste. Off-site transport and disposal could significantly increase this estimate. Section 4 describes the assumptions and procedures used in determining the technology costs.

Section 2.0

Introduction

This section of the Applications Analysis Report includes a description of the Superfund Innovative Technology Evaluation Program, a discussion of the specific purpose of this report, and a general description of the hazardous waste remediation technology developed by Silicate Technology Corporation (STC).

2.1 Purpose, History, and Goals of the SITE Program

The Superfund Amendments and Reauthorization Act of 1986 (SARA) prompted two offices of the U.S. Environmental Protection Agency (EPA), the Office of Solid Waste and Emergency Response (OSWER) and the Office of Research and Development (ORD), to establish a formal program called the Superfund Innovative Technology Evaluation (SITE) Program. This program promotes the development and use of innovative technologies to clean up hazardous waste sites across the country. The primary purpose of the SITE Program is to enhance the development and demonstration, and thereby promote the commercial availability, of innovative technologies applicable to Superfund sites. The major goals of the SITE Program are:

- Identify and remove impediments to the development and commercial use of alternative technologies.
- Demonstrate the more promising innovative technologies in order to establish reliable performance and cost information for site cleanup decision making.
- Develop procedures and policies that encourage selection of available alternative treatment remedies at Superfund sites.
- Structure a development program that nurtures emerging technologies.

EPA recognizes that a number of factors inhibit the expanded use of alternative technologies at Superfund sites. One of the objectives of the program is to identify these impediments and remove them or develop methods to promote the expanded use of alternative technologies. Another objective of the SITE Program is to demonstrate and evaluate selected technologies. This is a significant ongoing effort that involves ORD, OSWER, EPA regional offices, and the private sector.

The SITE program is comprised of four component programs including:

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

This report is a product of the SITE Demonstration Program, which is designed to test field-ready technologies and provide reliable engineering performance and cost data on selected alternative hazardous waste remediation technologies. Developers of innovative waste cleanup technologies apply to the demonstration program by responding to EPA's annual request for proposals (RFP). Each annual round of demonstrations includes approximately 10 new technologies. To qualify for the program, a new technology must be at the pilot- or full-scale stage of development and offer some advantage over existing cleanup technologies. Mobile technologies are of particular interest to EPA. Proposals are evaluated by OSWER and ORD staff to select

or determine those technologies with the most promise for use at hazardous waste sites. Once a proposal has been accepted, a cooperative agreement between EPA and the developer is established to set forth responsibilities for conducting the demonstration and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site, and assuming all 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.

Demonstrations are conducted at hazardous waste sites (usually Superfund sites) or under conditions that closely simulate actual wastes and conditions, to ensure accuracy and reliability of information collected. Data obtained during a demonstration are used to evaluate the performance of the technology and potential operating problems, in addition to assessing estimated capital and operating costs. Demonstration data also provide useful information for estimating long-term operating and maintenance costs and evaluating long-term risks in using the technology.

The other three component SITE Programs listed above focus primarily on fostering further investigations and development of treatment technologies that are still at the laboratory scale through the Emerging Technologies Program, and providing assistance in the development and demonstration of innovative monitoring and site characterization technologies through the Measurement and Monitoring Technologies Program. Finally, the Technology Transfer Program prepares a variety of publications including reports, videos, bulletins, and project summaries. This information is distributed to the user community to provide reliable technical data for use by decisionmakers, such as remedial project managers and facility managers in selecting remedial technologies, and to promote the technology's commercial use.

2.2 SITE Demonstration Documentation

Results of the STC SITE demonstration project are contained in two documents, the Technology Evaluation Report (TER) and the Applications Analysis Report (AAR). The TER presents demonstration testing procedures, data, and quality assurance/quality control standards, and it also provides a comprehensive description of the demonstration and its results. The TER parallels the AAR and is intended for technical professionals making detailed evaluations of the technology for a specific site and waste situation.

The AAR evaluates available information on the specific technology and analyzes its overall applicability to other situations with different site characteristics, waste types, and waste matrices. This report summarizes the results of the SITE demonstration, the vendor's design and test data, and other laboratory and field applications of the technology. It discusses the advantages, disadvantages, and limitations of the technology. Costs of the technology for different applications are estimated based on available data from this and other similar SITE demonstrations. The report also discusses the factors, such as site and waste characteristics, that have a major effect on costs and performance.

2.3 Purpose of the Applications Analysis Report

The purpose of the AAR is to estimate, based on available data, the applicability and costs of a technology for Superfund and RCRA hazardous waste site remediations. This report is intended for the decisionmakers responsible for implementing specific remedial actions and helps them determine whether a technology has merit as an option for a particular cleanup situation.

There are, however, limits to conclusions regarding Superfund applications that can be drawn from a single field demonstration. The successful demonstration of a technology at one site does not assure that a technology will be widely applicable or fully developed for commercial use. Data obtained from this demonstration may have to be extrapolated to estimate the total operating range of the technology. The extrapolation can be based on both demonstration data and other information available on the technology, including case studies of varying waste contamination.

The Applications Analysis Report attempts to synthesize existing information and draw reasonable conclusions. This document will be useful to those considering the technology for Superfund cleanup and represents a critical step in the development and commercialization of the treatment technology. If a candidate technology

appears to be suitable for a specific site, a more thorough analysis would be made based on the TER and on available information from remedial investigations for the specific site.

2.4 Technology Description

STC's contaminated soil process utilizes silicate compounds to chemically stabilize organic and inorganic constituents in contaminated soils and sludges. The vendor claims that proprietary silicate reagents adsorb and chemically fix organic and inorganic contaminants prior to solidifying the waste with a cementitious material resulting in a high-strength, leach-resistant monolith. Treatability studies and site investigations are conducted to determine the necessary type and amounts of reagents according to the waste characteristics. The following sections discuss information provided by STC and include the general treatment process chemistry and major process equipment needed for the STC technology. Specific procedures used in the SITE demonstration are detailed in Appendix B.

2.4.1 Process Chemistry

STC has developed two groups of reagents: SOILSORB HM for treating wastes with inorganic constituents and SOILSORB HC for treating wastes with organic constituents. These two groups of reagents can be combined to treat wastes containing both organic and inorganic contaminants.

Stabilization of wastes with inorganic constituents involves silicate-forming reactions resulting in the incorporation of heavy-metal ions into the crystal lattice structure of a highly insoluble calcium-alumino-silicate compound. The reactions effectively immobilize the contaminants, thereby reducing the potential for leaching. A silicate solidifying agent microencapsulates the alumino-silicate compound to form another physical barrier to leaching. The result is a very stable compound analogous to common rock-forming silicate minerals.

STC's technology for treating organic wastes utilizes a three-step process in which organic compounds in the waste are sequestered by a modified alumino-silicate mineral. The silicate is surface-modified with organic compounds, creating a layered structure that consists of organic layers sandwiched between the alumino-silicate layers. Upon mixing with the organic wastes, this modified silicate bonds organic contaminants into the layers of the organically surface-modified alumino-silicate compound through a partitioning reaction. STC claims that the organic layers of the modified silicate can adsorb as much as 20 times their own weight of organic constituents.

The first step of the contaminant stabilization process involves partitioning similar to a liquid/liquid extraction. If a water-immiscible oil and water that contains a polynuclear aromatic compound such as anthracene are combined, the anthracene will migrate into the oil phase and remain there. STC's immobilization technology is based on this concept except that it utilizes a solid organic phase instead of oil. This partitioning follows basic laws of physical chemistry and can in general terms be predicted for any organic compound based on its water solubility.

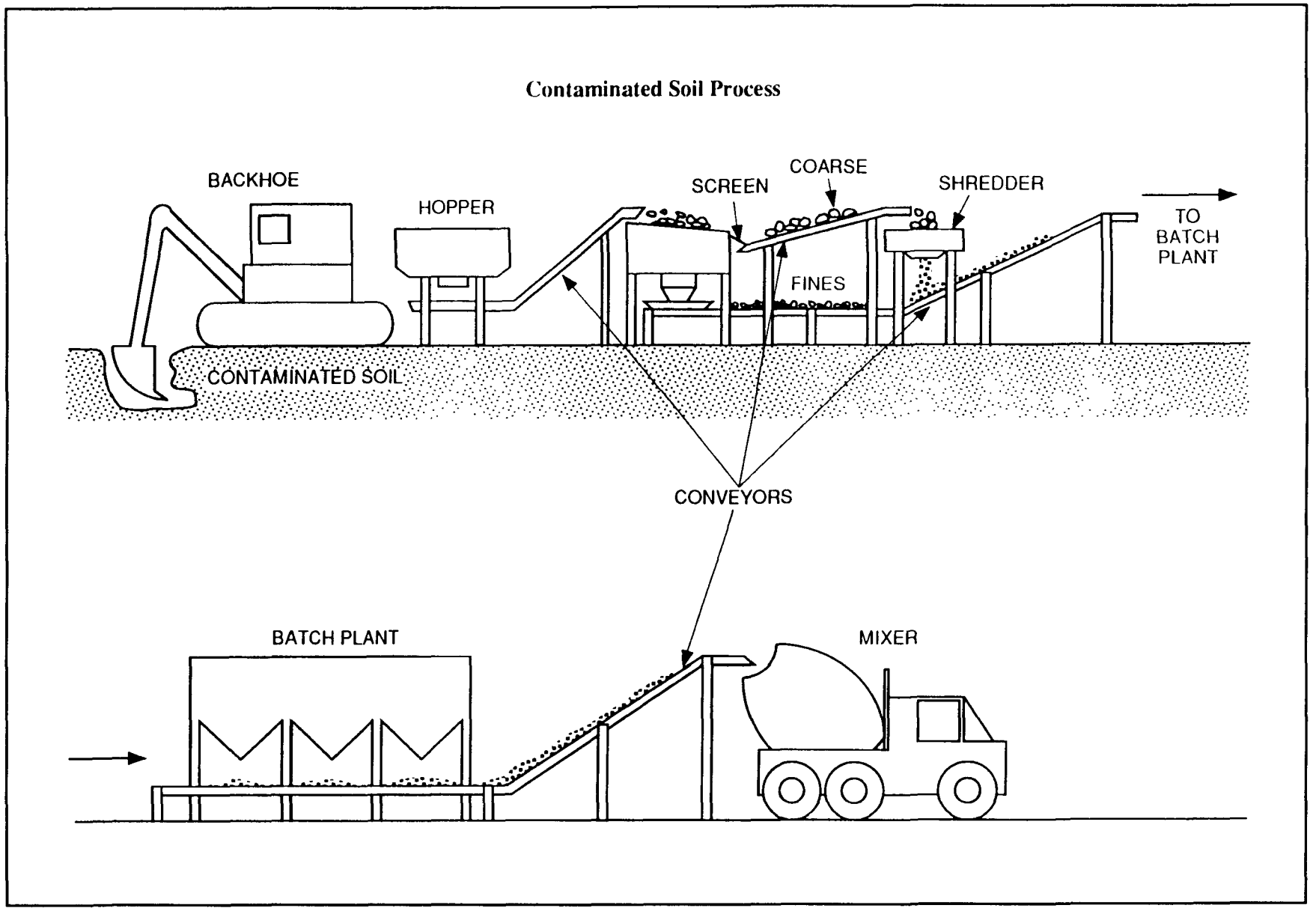
The second step of stabilization involves the morphology of the alumino-silicate structure. As the organic constituents partition to the organic layers of the surface-modified silicate, the layered alumino-silicate plates tend to bond with the surface of the waste, thereby creating a physical barrier and thus reducing leachability.

Finally, the third step is the addition of STC's proprietary silicate solidifying agent, which microencapsulates the layered alumino-silicate structure and bonds the solidifying agent to the exposed layered-silicate surfaces. This microencapsulation of the adsorbed organics further reduces leachability by forming another physical barrier to leaching. The alumino-silicates used for the organic partitioning reaction and the silicates used for the microencapsulation reaction can be shown to be thermodynamically stable compounds, analogous to common, rock-forming silicate minerals. The vendor-claimed durability will be tested in the long-term storage phase of this demonstration.

2.4.2 Process Equipment

Treatment of contaminated soil (Figure 2-1) typically begins with the separation of coarse material from fine material in a mechanical separator. This is accomplished using a shaker screen to separate the coarse material greater than 3/8 inch in diameter. This coarse material

Figure 2-1. Schematic for STC Treatment Process



is sent through a shredder or crusher, which reduces the waste material to less than 3/8 inch. The screened waste is loaded into a batch plant where it is weighed and the appropriate amount of silicate reagents determined during treatability testing are added. This mixture is conveyed to a pug mill mixer (or equivalent, such as a ready-mix cement truck) where water is added and the mixture is thoroughly blended. Sludges are placed directly into the pug mill for addition of reagents and mixing. The amount of reagents required for stabilization can be adjusted according to variations in organic and inorganic contaminant concentrations determined during treatability testing. The mixing process continues until the operator determines that the waste and the added reagents are thoroughly homogenized, up to approximately 60 minutes per batch. The treated material is then placed in confining pits for on-site curing, or cast into molds for transport and disposal off site.

Hardware for the treatment process includes processing and materials-handling equipment. With the exception of STC's liquid reagent metering equipment, conventional construction equipment readily available for purchase or rental in most areas can be used. Such equipment typically would have the capacity to treat up to 40 cubic yards of contaminated soil per day; however, only 2.5 cubic yards per day were processed during this demonstration.

Process equipment for soil treatment using STC's technology includes the following:

- Pretreatment screen -- Pretreatment screening is normally accomplished with a shaker screen to separate fine (<3/8 inch in diameter) from coarse material (>3/8 inch in diameter). Pretreatment screening down to 0.04 - 0.08 inch (1-2 mm) diameter was required for the STC demonstration since a crusher was not used, and it was necessary to ensure that individual aggregates of untreated waste did not bias the chemical analyses.

- Crusher or shredder -- A crusher or shredder is used to further reduce waste aggregate size prior to mixing, if necessary.

- Weight conveyor -- The weight conveyor is used to weigh and transfer screened material to the pug mill.

- Pug mill -- A pug mill, cement-mixer, or other conventional construction equipment can be used as a mixing vessel.

- Liquid reagent metering equipment -- Liquid reagent metering is accomplished with STC's mobile liquid meter, which is mounted on a 20-foot bed trailer. This equipment includes two 500-gallon tanks.

Materials-handling equipment for soil treatment includes the following:

- Front-end loader/backhoe for excavation and transport of waste material on site.

- All-terrain forklift for moving 1.5- to 2-ton forms filled with treated waste, if needed.

2.5 Key Contacts for the SITE Demonstration

Additional information concerning the STC solidification/stabilization treatment process or the SITE Program can be obtained from the following sources:

The STC Technology:

Mr. Steve Pegler or Mr. Greg Maupin
Silicate Technology Corporation
7655 E. Gelding Rd.
Scottsdale, Arizona 85260
(602) 948-7100

The SITE Program:

Mr. Edward R. Bates
Superfund Technology Demonstration Division
U.S. EPA Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, Ohio 45268
(513) 569-7774

Section 3.0

Technology Applications Analysis

This section addresses the applicability of the STC immobilization (i.e., solidification/stabilization) technology for the treatment of contaminated soil containing heavy metals and pentachlorophenol (PCP). For purposes of this report, "solidification" is defined as the physical consolidation of contaminated soil into a hard, rock-like material. "Stabilization" is defined as the chemical containment of hazardous contaminants. This discussion is based upon the results of the SITE demonstration performed at the Selma Pressure Treating (SPT) wood preserving site in Selma, California, and a series of other applications of the technology. The vendor's claims concerning the capabilities of the STC solidification/stabilization treatment process are presented in Appendix A. A complete discussion of the results of the SITE demonstration is included in Appendix B. The results from five case studies documenting the use of the STC technology are presented in Appendix C.

Included in this section is a summary of the effectiveness of the STC solidification/stabilization treatment process followed by discussions of the characteristics of the SPT site, the materials-handling requirements for the STC technology, personnel requirements, potential community exposures resulting from application of the STC technology, and potential regulatory requirements that may pertain to use of the technology.

3.1 SITE Demonstration Results

The STC solidification/stabilization treatment process was used to treat contaminated soils reported to contain elevated concentrations of PCP (1,900 to 8,400 ppm), arsenic (375 to 1,900 ppm), chromium (1,900 ppm), and copper (1,500 ppm) (CDM, 1989 and U.S. EPA, 1990a). A summary of the results for other parameters is found in Appendix B.

In general, the objectives of the STC SITE demonstration were as follows:

- Assess the technology's ability to stabilize organic and inorganic contaminants.
- Assess the structural characteristics of the solidified waste and effectiveness of stabilization over a 3-year period.
- Determine volume and density increases resulting from the treatment process.
- Develop information required to estimate the capital and operating costs for the treatment system.

The field demonstration of the STC technology was conducted over a period of 6 days. The first day consisted of processing a reagent-blank mixture batch that included clean sand, water, and STC's proprietary SOILSORB reagents (P-4 and P-27). On days 2 through 6, STC treated five 2.5-cubic-yard batches of contaminated soil. Table 3-1 lists the operating parameters for the STC SITE demonstration. Batch 2 was not further analyzed due to mixing problems resulting in significant inhomogeneity of the treated waste.

The key findings of the demonstration are given below; a more detailed discussion is provided in Appendix B. All percent reductions cited take into account the effects of dilution due to the addition of treatment reagents.

A summary of the total waste analyses (TWA) for the inorganic contaminants of regulatory concern at the SPT site, as well as PCP is shown in Table 3-2. Raw waste concentrations

Table 3-1. Operating Parameters for the STC SITE Demonstration

Parameters	Batch					
	RM	1	2	3	4	5
Waste soil weight (lbs)	0	5,000	5,000	4,000	4,000	4,464
Silica sand weight (lbs)	1,972	0	0	0	0	0
Dry reagent weight (lbs)	695	1,732	1,723	1,382	1,413	1,638
Water added (lbs)	422	2,172	3,850	1,713	1,760	1,759
Water lost during curing (lbs)	NA	97	NA	41	71	67
Mixer power (hp)	29	29	29	29	29	29
Current to mixer (amp-hr)	17	83	77	77	248	79
Pretreatment mixing time (min)	0	50	60	60	270	60
Treatment mixing time (min)	22	60	40	40	60	45
Additives ratio[a]	NC	0.761	NC	0.764	0.776	0.746

RM = Reagent mixture
NA = Not analyzed
NC = Not calculated
a = The additives ratio is the mass of additives including water of hydration, divided by the mass of wastes.

Table 3-2. Summary of TWA Data

Constituent	Ranges of Concentrations (ppm) (Batches 1, 3, 4, and 5)		Ranges of Percent Reduction
	Raw Waste	Treated Waste	
Arsenic	270 - 2,200	200 - 1,600	-29 - (-4)
Chromium	340 - 2,100	270 - 1,300	-48 - 4
Copper	330 - 1,300	210 - 780	-32 - 4
PCP	2,000 - 8,300	80 - 170	91 - 97

ranged from 270 to 2,200 ppm for arsenic; 340 to 2,100 ppm for chromium; and 330 to 1,300 ppm for copper. Treated waste TWA results show slightly decreased concentrations for each of these analytes. Taking into account the dilution factor due to the added reagents, TWA results indicate mostly negative percent reductions. As discussed in more detail in the TER, increased *total* metal concentrations following treatment is presumed to be a result of differences in extraction efficiencies relative to the specific raw or treated waste matrix. However, the STC treatment process was not expected to destroy inorganic contaminants, but rather immobilize them from leaching. Therefore, although TWA for selected inorganics were evaluated to compare total contaminant concentrations with leachate concentrations, the TWA is not considered a useful criteria for the inorganic analytes. PCP concentrations in the raw waste ranged from 2,000 to 8,300 ppm, with the treated waste concentrations ranging from 80 to 170 ppm. Percent reductions for PCP ranged from 91 to 97 percent, indicating that the STC treatment process was effective in treating the organic component of the SPT waste.

Tables 3-3 and 3-4 summarize TCLP and TCLP-Distilled Water results, respectively. Leach tests conducted on the SPT waste show significant percent reductions in the leachate from the raw waste to the leachate in the treated waste for several of the critical analytes. Percent reductions for arsenic ranged from 35 to 92 percent as measured by the TCLP, and 98 percent based on the TCLP-Distilled Water test. Percent reductions of copper concentrations in the leachate, although not a target analyte for treatment, ranged from 90 to 99 percent when evaluated using the TCLP, and from 86 to 90 percent based on the TCLP-Distilled Water test. Chromium was also not a target analyte for treatment because of very low leachable concentrations. Nevertheless, chromium concentrations in the raw waste leachates were reduced by up to 54 percent based on the TCLP-Distilled Water test results; however, due to the very low concentrations of chromium in the raw and treated waste TCLP leachates, no significant conclusions could be drawn concerning the leachability of chromium upon treatment as measured by the TCLP test. Concentrations of PCP in the leachate from the TCLP test showed increases upon treatment for two batches resulting in percent reductions ranging from -460 to greater than 81 percent, whereas the TCLP-Distilled Water test showed percent reductions of 80 to 97 percent from the raw waste to the treated waste.

Table 3-5 summarizes CALWET results for both the raw and treated wastes. In general, the CALWET consists of an extraction similar to that of the TCLP extraction, except that the CALWET uses a citric acid leaching solution for a period of 48 hours at a liquid-to-solid ratio of 10 to 1. This procedure is a more aggressive leaching procedure since it uses a stronger leaching solution for a longer period of time. The results from the CALWET method showed very large negative percent reductions and in several cases showed increased leachability of the analytes from the raw to the treated wastes. Specifically, chromium and PCP showed greater leachate concentrations in the treated wastes than in the raw wastes. Arsenic and copper showed decreased leachate concentrations, but percent reductions were low when accounting for dilution. Overall, due to the inconsistent and erratic trends in the results of the CALWET procedure, conclusions that can be drawn regarding the effectiveness of the STC stabilization process are based on achieving California thresholds as described below.

Federal and state of California regulatory thresholds for the TCLP and CALWET methods are shown in Table 3-6. The concentrations of arsenic, total chromium, and PCP were all below federal regulatory threshold levels for the TCLP in both the raw and treated wastes. Federal threshold values for copper and hexavalent chromium have not been established. California regulatory thresholds are presented for total threshold limit concentrations (TTLC) utilizing TWA concentrations, and for solubility threshold limit concentrations (STLC) for the CALWET leach method. In general, arsenic and PCP exceeded the TTLC for both the raw and treated wastes. Total chromium and copper were below TTLC levels for both raw and treated wastes. CALWET leach data reveal more variable trends with arsenic and copper ranging from below to above threshold levels, PCP well above STLC levels, and total chromium well below the regulatory levels for both raw and treated wastes. In the state of California, regulatory levels are specified both as total chromium (including trivalent and hexavalent species) and as hexavalent chromium; however, data for hexavalent chromium was not available. Thus, the STC

Table 3-3. Summary of TCLP Data

Constituent	Ranges of Concentrations (ppm) (Batches 1, 3, 4, and 5)		Ranges of Percent Reduction
	Raw Waste	Treated Waste	
Arsenic	1.1 - 3.3	0.09 - 0.88	35 - 92
Chromium[a]	< 0.05 - 0.27	0.19 - 0.32	-390 - (-110)
Copper[a]	1.4 - 9.4	0.06 - 0.10	90 - 99
PCP	1.5 - 2.3	< 0.25 - 5.5	-460 - >81

[a] *Analyte not a target for treatment.*

Table 3-4. Summary of TCLP-Distilled Water Data

Constituent	Ranges of Concentrations (ppm) (Batches 1, 3, 4, and 5)		Ranges of Percent Reduction
	Raw Waste	Treated Waste	
Arsenic	0.73 - 1.3	< 0.010 - 0.012	>98
Chromium[a]	0.07 - 0.19	< 0.050 - 0.079	-42 - 54
Copper[a]	0.37 - 0.99	0.030 - 0.054	86 - 90
PCP	35 - 80	0.58 - 4.0	80 - 97

[a] *Analyte not a target for treatment.*

Table 3-5. Summary of CALWET Data

Constituent	Ranges of Concentrations (ppm) (Batches 1, 3, 4, and 5)		Ranges of Percent Reduction
	Raw Waste	Treated Waste	
Arsenic	8.8 - 29	4.6 - 23	-44 - 37
Chromium[a]	2.1 - 7.1	3.8 - 19	-380 - (-210)
Copper[a]	18 - 61	8.8 - 33	2 - 22
PCP	2.3 - 3.2	3.5 - 32	-1,800 - (-140)

[a] *Analyte not a target for treatment.*

Table 3-6. Regulatory Thresholds for Critical Analytes of the SPT Waste

Constituents	Federal	State of California	
	FRTL (mg/L)[a]	TTLC (mg/kg)[b]	STLC (mg/L)[c]
Arsenic	5.0	500	5.0
Chromium (hexavalent)	---	500	5.0
Chromium (total)	5.0	2,500	560
Copper	---	2,500	25
PCP	100	17	1.7

a = Federal Regulatory Threshold Limit, based on TCLP.
b = Total Threshold Limit Concentration, based on TWA.
c = Solubility Threshold Limit Concentration, based on CALWET.

solidification/stabilization treatment process did not consistently achieve California leaching (CALWET) requirements for the treated wastes. In addition, the treatment process also did not lower total concentrations for contaminants that exceeded California's TTLC in the raw waste (i.e., arsenic and PCP); however, immobilization processes are not intended to reduce total contaminant concentrations, but to reduce leachable concentrations. Finally, TCLP leachate concentrations were already below federal threshold TCLP levels prior to treatment.

The short-term structural characteristics of the treated waste appeared to be suitable for the waste to be placed in a hazardous waste landfill, assuming appropriate environmental regulations are met (e.g., land disposal restrictions under RCRA). The permeability of the treated waste was relatively low. Permeability values shown in Table 3-7 ranged from 0.33×10^{-7} to 2.5×10^{-7} cm/sec. For comparison, these values are of the same order of magnitude as clays used in the construction of bottom liners for hazardous waste landfills. Table 3-8 summarizes unconfined compressive strengths (UCS) for the treated wastes and compares the values to both EPA minimum recommendations for placement in a hazardous waste landfill and American Society for Testing and Materials (ASTM)/American Concrete Institute (ACI) standards for concrete. UCS values of the treated waste ranged from 170 to 720 psi; these values are above EPA's minimum recommendation of 50 psi for UCS for stabilized wastes to be disposed of in a hazardous waste landfill (U.S. EPA, 1986a). However, these UCS values are well below the minimum ASTM/ACI standard of 3,000 psi for use in construction of concrete sidewalks (ASTM, 1991). (STC claims that waste treated by its technology can be made to meet requirements for construction applications, if desired.)

Table 3-9 presents the volume of raw waste and treated waste for each of the batches analyzed, along with calculated percent increases. For each batch the volume of the treated waste was greater than the volume of the raw waste due to the addition of STC's proprietary reagents. The volume increases for the four batches ranged from 59 to 75 percent (68 percent average).

The long-term stabilization and solidification effectiveness of the STC technology will be monitored over a 3-year period. Samples of treated material from the SPT site were analyzed using the TCLP and TWA tests at 6 and 18 months following the demonstration. In addition, UCS was analyzed after 18 months. Results of the first round of TCLP and TWA tests, 6 months after the demonstration, showed higher average leachate concentrations of arsenic, chromium, copper, and higher extract concentrations of PCP than reported after the initial 28-day sample curing. The long-term results for arsenic and chromium were, however, still within federal regulatory threshold levels for these metals. The 18-month analyses showed

Table 3-7. Summary of Permeability Data

Batch	Ranges of Permeability (cm/sec)	Requirement for Bottom Liners for Hazardous Waste Landfills (cm/sec)
1	1.30×10^{-7} - 2.1×10^{-7}	1.0×10^{-7}
3	0.52×10^{-7} - 2.5×10^{-7}	
4	0.49×10^{-7} - 1.3×10^{-7}	
5	0.33×10^{-7} - 1.3×10^{-7}	

Table 3-8. Summary of Unconfined Compressive Strength Data

Batch	UCS (psi)	EPA Minimum Recommended UCS for Placement in a Hazardous Waste Landfill (psi)	Minimum ASTM/ACI Standard for Concrete (psi)
1	190 - 720	50	3,000
3	250 - 320		
4	170 - 380		
5	250 - 430		

Table 3-9. Summary of Volume Increase for STC-Treated Waste

Batch	Volume of Raw Waste (ft^3)	Volume of Treated Waste (ft^3)	Percent Increase
1	56	90	59
3	41	73	75
4	42	72	73
5	46	77	66

improved percent reductions for arsenic, averaging 88 percent reduction, and PCP, averaging 96 percent reduction. Chromium and copper concentrations in the TCLP-leachates continued to increase over the 18-month time period. UCS tests showed an average 71 percent increase in physical strength for the STC-treated waste in 18 months. Appendix B contains a more detailed analysis of these results. Additional long-term (18-month) weathering studies from exposed monoliths of the STC-treated waste are discussed in the TER. Final results for the long-term monitoring, including 36-month chemical, leaching, and strength tests, will be available from EPA upon completion of the analyses.

The process equipment used during the technology evaluation was observed to be mechanically reliable. No equipment-related problems occurred during the 6-day demonstration. In addition, the process equipment used during the demonstration was capable of mixing all components, including the waste material, into a homogeneous, solidified product, provided that the pretreatment screening or size reduction of surface hardpan material down to 0.04-0.08

inch (1-2 mm) diameter was conducted.

3.2 Summary of Case Studies

The following summary of five case studies provides additional information on the STC solidification/stabilization treatment technology. The information available for these case studies pertains mainly to chemical data obtained from preliminary treatability studies. Very little information was provided pertaining to system performance or costs. Detailed results and additional discussions are presented in Appendix C.

Prior to selection of the STC SITE demonstration location at SPT, contaminated soils from the Tacoma Tar Pits, Purity Oil, and Kaiser Steel facilities were subjected to preliminary pilot-and bench-scale treatability testing. These soils were generally contaminated with both organic and inorganic constituents.

The treatability tests from the Tacoma Tar Pits facility yielded reductions ranging from 89 to 99 percent for TCLP analyses of cadmium, copper, nickel, lead, and zinc, with EP Toxicity percent reductions in excess of 90 percent for nickel and zinc. Up to 11 of 26 semivolatile organics, and up to six volatile organics showed reductions for TCLP analyses. However, the tests did not include measures to quantify volatiles that may have been lost due to mixing and curing. The EP Toxicity test yielded reductions for up to 10 semivolatile organics and up to six metals. TWA for semivolatiles yielded slight to moderate reductions for up to 20 of 26 semivolatiles analyzed.

STC's immobilization technology yielded reductions in leachate concentrations for 10 of 12 metals analyzed at the Purity Oil Facility. Greater than 95 percent reduction was achieved for TCLP lead and cadmium analyses. Chromium showed percent reductions greater than 56 percent for the TCLP. STC's technology also yielded reductions in leachate concentrations for two of eleven volatile organics, and three of six semivolatile organics based on the TCLP. However, the tests did not include measures to quantify volatiles that may have been air-stripped. Percent reductions for the organic contaminants naphthalene, phenanthrene, flouranthene, 2-methylnaphthalene at the Kaiser Steel Facility were in excess of 78 percent based on TWA. Additional studies to determine the optimum reagent-to-waste ratios for the TCLP were also performed at the Kaiser Steel and Purity Oil Facilities.

Treatability results from lead-contaminated soils at the Brown's Battery Breaking Superfund SITE near Reading, Pennsylvania indicate stabilization of lead at concentrations up to 53,600 ppm in the samples analyzed; however, because dilution factors were not reported, contaminant reduction percentages could not be determined.

Post-treatment verification laboratory results from the Lion Oil Refinery, El Dorado, Arkansas, indicate that contaminated refinery sludge was treated for selected metals, volatile and semivolatile organics. In all but two cases, the metals and organics analyzed were below detection limits for the treated wastes; however concentrations for the raw waste sludge were not available for this report. Results for the solidification of the waste sludge show that the greatest unconfined compressive strengths were obtained by using 70 to 80 percent sludge (by weight) in addition to 7 to 11 percent cement and 1.4 to 2.4 percent STC proprietary reagents.

3.3 Factors Influencing Performance and Cost Effectiveness

Several factors can influence the performance and cost effectiveness of the STC immobilization technology; remedial project managers or facility managers should consider these factors when deciding whether to use the STC technology. These factors can be grouped into four main categories: (1) waste characteristics; (2) volume/density increase; (3) operating conditions; and (4) climate and curing conditions. The following subsections discuss these categories in detail.

3.3.1 Waste Characteristics

Waste characteristics that may affect the performance of the STC immobilization technology include clay content, coal and lignite content, moisture content, oil and grease content, pH of the waste, volatile organic concentrations, and aggregate size of the waste (STC, 1991). Wastes with high clay content (>50 percent) may release clay into the mixing water which may

result in a large concentration of these particles near the surface of the solidified matrix, producing an inferior quality matrix. Coal and lignite in excess of 1 percent may also impair the quality of the solidified waste mixture. Wastes with very high moisture contents should be treated as sludges and may therefore require larger amounts of reagents for solidification.

Oil and grease (and other nonpolar organics) may have deleterious effects on the ability of a matrix to set, and thus may reduce the unconfined compressive strength of the treated waste. STC reports that levels of up to 60 percent oil and grease have been successfully treated (STC, 1991). Low-pH wastes (e.g., acid sludges) may react with the relatively higher pH materials used in the reagent mixture, resulting in incomplete solidification. Such wastes must be neutralized prior to treatment.

For wastes with large aggregate sizes, incomplete mixing may occur which can result in pockets of untreated waste within an otherwise homogeneous waste/reagent mixture. Well-graded raw wastes (i.e., wastes with several different particle sizes) will form more stable monolithic blocks than poorly-graded (one-sized) raw wastes. Additional screening and size reduction of the SPT contaminated soil aggregates down to 0.04 - 0.08 inch (1-2 mm) diameter was also necessary to ensure that individual aggregates did not bias the chemical analyses.

Wastes containing volatile organics may release these organics during the mixing process, resulting in artificially high percent reductions for these constituents. In addition, the concentrations of metals or semivolatile organics in the waste may impair the ability to meet desired levels of these constituents in the treated waste. For example, if the objective of the treatment is to render waste nonhazardous, the higher the contaminant concentration in the raw waste, the higher the concentration in the treated waste, and even after 90 percent reduction in TWA or leachate concentrations, the technology may not be appropriate for some wastes because the wastes may still be considered hazardous after treatment.

3.3.2 Volume/Density Increase

Average volume increases of 68 percent were observed after treatment of the SPT waste. The volume increase depends on the characteristics of the waste treated and the desired performance specifications. The bulk densities of the wastes increased only 0.6 to 11 percent, with an average increase of 5.5 percent resulting from the addition of reagents during treatment. For on-site disposal, the above volume increases may be desirable in situations where additional soil material would be needed for filling-in and leveling depressions. The increased volume could reduce the costs of purchasing and transporting fill material to the site. The STC immobilization technology may be less desirable for use in treating wastes as the ratio of the volume of the treated waste to the volume of the raw waste increases. Off-site disposal of treated wastes becomes more difficult and costly with increasing volume since disposal costs are usually on a total weight or unit volume basis.

3.3.3 Operating Conditions

Operating parameters for the STC solidification/stabilization treatment process include mixer power, mixing time, added reagents, and the additive ratios for the reagents, as shown in Table 3-1. Any of these operating conditions can be modified to accommodate differences in waste characteristics. Operating conditions can also be modified to yield treated waste better suited for a particular disposal option or use.

The power delivered to the mixer affects the degree of mixing of the waste. Wastes that are exceptionally viscous or that have larger particle or aggregate sizes may require a larger power output by the mixer. Remedial project managers or facility managers should consider the power output of the mixer when evaluating which mixer to use to treat a particular waste.

An inordinately long pre-mixing time (4.5 hours) for Batch 4 prior to the addition of the reagents may have caused the anomalously high arsenite concentration in the raw waste for this batch (see Table B-2). Although precise chemical information necessary to determine the reactions that took place were not available, ion-speciation shows that Batch 4 contained greater quantities of the arsenic ion-species arsenite (III) than the other batches analyzed. Reduction from

the more stable arsenate (V) species may have resulted during the pre-mixing process if at least one other element was oxidized, thereby balancing the oxidation/reduction reaction. Such differences in chemical characteristics of the waste may be the reason for the very low percent reduction of arsenic in Batch 4 under acidic TCLP conditions, since arsenite (III) is more mobile in acidic soil environments than arsenate (V) (Dragun, 1988).

The additives ratio for the process can be varied to account for differences in the composition of certain wastes. For example, the volume of water added to the process should be adjusted to account for the moisture content of the waste. As mentioned earlier, certain waste streams with high moisture content may not be easily treated using solidification/stabilization. Therefore, the amount of water used in the treatment process should be decreased with increasing water content of the waste to be treated.

3.3.4 Climate and Curing Conditions

The curing temperature and the curing time will have an effect on the chemical and physical characteristics of the treated waste. In general, treated wastes cured at higher temperatures will cure faster, but the higher temperatures may enhance organic loss by volatilization. In addition, the treated waste may not have the equivalent structural integrity to that of wastes cured at a lower temperature. (An exception to this would be wastes that are cured at temperatures at or below freezing.) In general, treated wastes cured at a constant room temperature will become increasingly stable with increasing time. Blocks of treated waste that are exposed to the effects of weather for an extended period of time may begin to break down as a result of weather conditions, including precipitation and freeze/thaw cycles. Solidified wastes should be allowed to cure for several weeks; ASTM guidelines for construction materials require a cure time of 28 days at 16° to 27°C (ASTM, 1991).

Below-freezing temperatures and heavy rain could have an adverse impact on the operation of the STC immobilization technology. If subfreezing temperatures are expected, the mixer and the water source should be insulated or heated to avoid freezing of the water used in the process. Raw materials, including the reagents, should be protected from precipitation.

3.4 Site Characteristics and Logistics

This section describes the treatment site characteristics and the logistical requirements for operating the STC immobilization technology. The following discussion also addresses site access; minimum requirements for utilities, equipment, and supplies; and services necessary for the STC technology.

3.4.1 Treatment Area

The area selected for application of the STC immobilization technology should be relatively level and must be large enough to accommodate necessary equipment. The area containing the mixing unit should also be level; it can be paved or covered with compacted soil or gravel. The site geotechnical characteristics (e.g., soil bearing capacity) should be evaluated to identify whether a foundation is necessary to support the mixer and ancillary equipment. During the SITE demonstration, a 35- by 15-foot area was needed to accommodate the 5-cubic-yard mixer. However, mixing unit sizes vary from smaller batch mixers (5 cubic yards) to large pug mill mixers (15 cubic yards). The treatment area must be large enough to place other equipment, such as tanks for the storage of reagents and rinsewater. A 6- by 10-foot area was needed for personnel decontamination. The area must also be large enough to allow for easy movement of large machinery (e.g., backhoes or bulldozers). In addition, approximately a 45- by 15-foot area is required for indoor office and laboratory space.

3.4.2 Site Access

Site access requirements for the treatment equipment are minimal. The site must be accessible to tractor-trailer trucks. The roadbed must be able to support such a vehicle for delivery of the mixer, storage tanks, and the office trailer.

3.4.3 Utilities

The STC immobilization technology requires water and electricity. Water is used as an additive in the treatment process and is required for equipment cleanup and personnel decontamination. The mixing unit used at the STC SITE demonstration required 480-volt, 3-phase, 500-

amp electrical service; however, electrical requirements will vary depending upon the type of mixer used. Additional electrical power (110-volt, single phase) is required for lighting, and heating or cooling any office trailer, and operating any on-site laboratory and office equipment. A telephone is useful to contact emergency services and to provide normal communications.

3.4.4 Equipment

The STC immobilization technology requires several pieces of major and auxiliary equipment including: a mixer, a bulldozer or a backhoe for the movement of contaminated material, a hopper and scale, tanks for the storage of decontamination water, a tank truck, a forklift for movement of treated waste, a tractor-trailer to transport heavy equipment, and an office trailer. In addition, if pretreatment waste aggregate size reduction is necessary, a screen and a crusher or shredder would also be required. Miscellaneous equipment needed would include a dumpster, a steam or high-pressure cleaner, a gasoline-powered electric generator if a local power source is not available, pumps, plastic sheeting, and personal protective equipment (PPE).

3.4.5 Supplies and Services

A number of supplies are required for application of the STC technology. Adequate supplies of the following are required: the STC SOILSORB reagents, personal protective equipment, and drums for the storage of contaminated materials. Plastic or other synthetic liners are also necessary to contain decontamination water until it can be placed in tanks or other storage. If necessary, receptacles (e.g., forms) for the treated waste must also be provided.

Services required on site may include laboratory services and sanitary facilities. Analytical equipment may be required on site (or off site through a contractual arrangement) for testing of the treated waste for physical properties or chemical constituents (e.g., unconfined compressive strength testing and TCLP analyses). Sanitation arrangements may include portable chemical toilets or other suitable sanitary facilities.

3.4.6 Personal Protective Equipment

The type and amount of PPE required for persons at sites where the STC immobilization technology is being used will vary depending on site conditions and duration of cleanup operation. Remedial project managers and facility managers should follow Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) guidelines (or state equivalents) where appropriate when selecting PPE. Material Safety Data Sheets (MSDS) recommend the use of NIOSH-approved respirators, tight fitting goggles, gloves, boots, and clothing to protect the skin from prolonged contact with the STC chemical reagents P-4 and P-27. The ingredients of P-4 and P-27 are not listed as containing carcinogens. At a minimum, facility personnel should always be outfitted in Level D protection. Where wastes that are being treated by the STC technology contain volatile organics, volatile metals, or particulate matter that may present an inhalation hazard, facility personnel should upgrade to Level C protection (respirator and protective clothing) or Level B protection (supplied air and protective clothing) where required.

3.5 Materials Handling Requirements

Materials handling under the STC immobilization technology includes requirements for handling untreated waste (contaminated soil or sludge) and treatment product and residuals. These two categories of wastes are discussed in detail in the following sections.

3.5.1 Pretreatment Materials Handling

The requirements for materials handling vary depending upon the type of waste to be treated. For some wastes, the only pretreatment materials handling required will be transfer of the contaminated material to the mixer. A size reduction step may be necessary to reduce the particle size of the waste to a maximum diameter of 3/8 inch to allow for sufficient mixing of the waste and the treatment reagents. At the SITE demonstration, this step was accomplished by forcing the material through a series of screens; these screens reduced the particles sizes of the waste to between 0.04 to 0.08 inch (1 to 2 mm) diameter to ensure that an individual aggregate of untreated waste did not bias the chemical analyses. Other options for size reduction of waste parti-

cles include crushers and grinders. Bench-scale treatability testing can provide information on size requirements, but often this can only be determined in the field. Remedial project managers and facility managers should investigate possible size reduction requirements prior to placing wastes into the mixing unit.

3.5.2 Residuals Handling

Several types of residuals are generated as a result of application of the STC immobilization technology. These residuals include (1) the monolithic blocks of treated waste; (2) contaminated PPE; (3) process and decontamination wastewater; and (4) other contaminated materials (e.g., plastic liners). Requirements for handling these residuals are discussed below.

The solidified blocks of treated waste may be handled on site or off site. Solidified wastes should be allowed to cure for 28 days prior to ultimate disposal (ASTM, 1991). The solidified wastes should be shielded from the effects of precipitation and temperature extremes to the maximum extent practicable during curing, including indoor storage or covering with tarps or plastic sheeting. On- and off-site disposal options include placement of the blocks in a landfill provided that appropriate environmental regulations are met.

Contaminated PPE and other contaminated debris may also be disposed of either on or off site. At the SITE demonstration, these materials were stored in 55-gallon drums until the drums could be sealed and prepared for disposal. The materials can then be disposed of in a landfill or incinerated either on site or off site in accordance with appropriate regulations.

The third class of residuals generated through use of the STC technology are process and decontamination wastewaters. Decontamination wastewaters may be recycled back into the process depending upon their composition. Decontamination wastewaters that cannot be reused can be sent off site for treatment or disposal. If discharge limitations are met and all necessary permits obtained, decontamination wastewaters can also be discharged on site into a sanitary sewer or to a surface water body.

3.6 Personnel Requirements

The STC immobilization technology may be operated with as few as eight people, but may involve several more persons depending on project size and site conditions. Two people must be skilled in the operation of heavy equipment, such as a bulldozer or backhoe, in order to move contaminated materials from the area of contamination to the mixer and to manage the treated waste. A third person is necessary to ensure that the proper amount of raw materials (e.g., reagents) are added to the process. A fourth person is needed to operate the mixer and oversee the mixing process. A fifth individual is required for sampling of the treated waste. A sixth person must be a trained individual to conduct air monitoring and to handle health and safety issues. Finally, two additional people are necessary: an overall coordinator and an off-site person to handle administrative requirements. Although eight persons may be considered as the minimum the technology can be operated with, in most cases it may be necessary to have more persons on site, especially during unusual weather conditions, such as extreme heat or cold, or when working with Levels B or C personal protective equipment becomes necessary. A security guard may also be required.

3.7 Potential Community Exposures

Community exposures to hazardous chemicals from the operation of STC's technology are expected to be minimal. Potential sources of community exposure may include particulate and volatile emissions from the pretreatment screening, crushing, and mixing processes. Particulate emissions are generated from the mixing of waste materials and reagents in the mixer. Volatile organics may also escape during on-site excavations and the mixing process if the mixing is performed in an open-air environment. Community exposures may be minimized by placing a tarp over the mixer when it is in operation.

3.8 Potential Regulatory Requirements

This section discusses environmental, health and safety, regulatory, and statutory requirements that may apply to STC's immobilization technology. The requirements that apply to STC's technology may vary depending upon the

location and type of site and the types of wastes or materials managed at the site.

3.8.1 Resource Conservation and Recovery Act (RCRA)

Subtitle C of RCRA, as amended by the Hazardous and Solid Waste Amendments (HSWA), provides for a comprehensive program to regulate the treatment, storage, transportation, and disposal of hazardous wastes. Hazardous wastes are defined in 40 CFR part 261 as wastes that are either (1) listed by EPA as hazardous wastes or (2) exhibit a characteristic of a hazardous waste. The lists of hazardous wastes are found in 40 CFR part 261, subpart D; the characteristics of hazardous wastes are described in 40 CFR part 261, subpart C.

Persons who generate wastes during the use of the STC immobilization technology must determine if the wastes are hazardous. Site personnel may make this determination by testing their waste or by using knowledge of the process generating the waste or knowledge of the properties of the waste. Wastes that are deemed hazardous are subject to both general and unit-specific regulations under RCRA. State regulations may also have additional criteria for the identification of hazardous wastes.

Raw waste treated using the STC technology may be classified as a hazardous waste. If the raw waste is a listed hazardous waste, then wastes generated from the treatment process (including the monolithic blocks of treated waste, decontamination water, contaminated debris, and contaminated PPE) will, in most cases, be listed hazardous wastes. If the raw waste exhibits a characteristic of a hazardous waste, wastes generated from treatment would only be hazardous if they continued to exhibit a characteristic. Residuals generated from the treatment of characteristic wastes must be evaluated to determine if they exhibit a characteristic by testing the residuals or using knowledge of the residuals' composition. In addition, residuals such as decontamination water can exhibit a characteristic of a hazardous waste even if the raw waste does not. The STC immobilization technology may not be a viable alternative if the treated waste is still regulated as a hazardous waste. If the raw waste or treatment residuals are nonhazardous wastes, certain state regulations may apply to the management of these wastes.

Under RCRA, certain requirements apply to the management of hazardous wastes. If hazardous wastes are generated on site, the management of these wastes must be in accordance with the requirements of 40 CFR part 262. If the raw waste is a hazardous waste, the facility would be required to also comply with the requirement for hazardous waste treatment, storage, and disposal facilities (TSDF) in 40 CFR Parts 264 or 265.

Both generators and treaters of hazardous waste must determine the applicability of the land disposal restrictions (LDR) to their hazardous wastes. The LDRs are expressed as treatment standards described in 40 CFR part 268, subpart D or statutory prohibitions in Section 3004(d) of RCRA. Wastes that are prohibited from land disposal under the LDRs may be land disposed only if the waste is treated so that treatment standards are met, or if a variance is obtained or a no-migration petition is granted. The STC immobilization technology may not be a viable treatment alternative if treatment residuals to be placed on the land do not meet LDRs treatment standards or prohibitions. In general, materials that are moved from within the boundaries of a land disposal unit are not subject to the LDRs. For example, wastes that are moved from one cell of a landfill to a different cell in the same landfill would not be subject to the LDRs, even though this activity constitutes placement of hazardous wastes on the land (which is normally the activity that triggers the LDRs). However, persons who use the STC technology should be aware of the potential applicability of the LDRs to activities associated with the use of the STC technology.

The treatment, storage, or disposal of hazardous wastes, with certain exceptions, requires a permit under RCRA (40 CFR 270.1(c)). Therefore, application of the STC technology at a site may require a RCRA Subtitle C permit if the material being treated is a hazardous waste. However, Section 121(e) of CERCLA may exempt certain on-site operations associated with remediations conducted under CERCLA from RCRA permitting requirements. All facilities seeking a permit under RCRA are also subject to the corrective action provisions of Section 3004(u) of RCRA; these provisions are designed to address releases of hazardous wastes or hazardous constituents from solid waste manage-

ment units at the facility.

3.8.2 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA), provides for federal authority to address releases of hazardous substances. Section 121 of SARA requires that remedies selected under CERCLA be protective of human health and the environment, be cost effective, and utilize permanent solutions. Section 121 states that remedies that utilize treatments that reduce the volume, toxicity, and mobility of waste are preferred over remedies that do not involve such treatment. Section 121 also mandates that cleanups conducted under CERCLA authority meet applicable or relevant and appropriate requirements (ARAR) under Federal and state statutes. SARA Section 121(d) provides for six waivers from ARARs:

- The remedial action selected is only part of a total remedial action that will attain ARARs.
- Compliance with ARARs at the facility will result in a greater threat to human health and the environment than alternative options.
- Compliance with ARARs is technically impracticable from an engineering perspective.
- The remedial action will achieve a standard of performance equivalent to that required under the ARARs through use of another approach.
- In the case of individual state ARARs, the state has not consistently applied the ARARs in similar circumstances at other remedial action sites.
- In the case of a remedial action conducted using CERCLA funds under the authority of Section 104 of CERCLA, the remedial action will not provide an amount of protection to human health and the environment commensurate with the amount of money that would be expended.

In order to meet the requirements of SARA Section 121, remedial project managers or facility managers that use the STC immobilization technology must comply with the substantive requirements of all ARARs; administrative requirements must only be met for off site actions. For example, blocks of treated (solidified) wastes that are disposed of on site must meet the requirements under the LDRs, but would not require a RCRA Subtitle C permit. Remedial project managers or facility managers should refer to EPA's "LDR Guides", July 1989 (OSWER 9347.3-01FS through 9347.3-06FS), for guidance concerning applicability of the LDRs to Superfund sites.

3.8.3 Toxic Substances Control Act (TSCA)

Requirements under the Toxic Substances Control Act (TSCA) may apply when treating wastes containing polychlorinated biphenyls (PCB) using the STC technology. TSCA regulates the manufacturing, processing, distribution, and use of items containing PCBs under the provisions of 40 CFR part 761; subpart D of part 761 regulates the disposal of PCBs. Liquid PCB wastes containing at least 50 ppm PCBs must be disposed of by using a high-efficiency boiler or an incinerator. Solid PCB wastes containing at least 50 ppm and less than or equal to 500 ppm PCBs must be incinerated or disposed of in a TSCA-approved landfill (40 CFR 761.75). Waste containing PCBs at concentrations greater than 500 ppm must be incinerated (40 CFR 761.65).

Sites where spills of PCBs have occurred after May 4, 1987, must be addressed under the PCB Spill Cleanup Policy in 40 CFR part 761, subpart G. In order to meet the requirements under the spill cleanup policy, wastes slated for treatment using the STC technology may require additional treatment, if the PCB spill cleanup standards are not met. The policy applies to spills of materials containing 50 ppm or greater PCBs and establishes cleanup protocols for addressing such releases based upon the volume and concentration of the spilled material.

3.8.4 Clean Water Act (CWA)

Requirements under the Clean Water Act (CWA) will generally apply to direct discharges

to surface waters or discharges to certain wastewater treatment plants. The CWA established two programs to regulate the discharge of pollutants into surface water bodies: the National Pollutant Discharge Elimination System (NPDES) program established under Section 402 of the CWA, and the pretreatment program for discharges to Publicly Owned Treatment Works (POTW) established under Section 307 of the CWA. The NPDES program establishes a system under regulations at 40 CFR part 122 to issue permits that specify effluent limitations for direct discharges to surface waters. The pretreatment program specifies general discharge prohibitions under regulations in 40 CFR part 403 and industry-specific discharge limitations in 40 CFR parts 405-699. Although no permits are required for discharges to a POTW, all discharge limitations, such as pretreatment standards established under the CWA, should be met prior to discharging wastewaters to a POTW. Local POTWs may also require permits or charge a fee for discharges to their wastewater treatment systems. Remedial project managers or facility managers should refer to "CERCLA Site Discharges to POTW", August 1990 (EPA/540/G-90/005) for further guidance. Wastewaters from the application of the STC technology must also be managed in accordance with any other applicable state and local discharge requirements that are more stringent or broader in scope than the NPDES and pretreatment programs.

3.8.5 Safe Drinking Water Act (SDWA)

The Safe Drinking Water Act (SDWA), as amended in 1986, includes the following programs: (1) drinking water standards, (2) underground injection control (UIC) program, and (3) sole-source aquifer and wellhead protection programs. Remedial project managers or facility managers should consider SDWA standards if wastewaters are being injected into the ground or if discharge is into an aquifer or surface water body used for drinking water. Underground injection of hazardous wastes into or above an underground source of drinking water is prohibited. Requirements under the SDWA may also be a concern if wastes from the STC process are placed in the ground. Decision-makers considering on-site disposal of residuals will have to consider local aquifer use and the potential for release of hazardous substances from the treated wastes into surface water and ground water.

3.8.6 Clean Air Act (CAA)

The Clean Air Act (CAA) provided EPA with the authority to establish emissions standards for hazardous air pollutants. Under the CAA, certain stationary sources of air pollutants are required to monitor for and, in some cases, restrict air emissions of hazardous air pollutants. Emissions from the STC solidification/stabilization treatment process are not likely to be regulated under the CAA, since the mixing unit is not likely to be classified as a major stationary source under the CAA under 40 CFR part 52.

Emissions from the STC treatment process typically include fugitive dust emissions as well as volatile organic compound (VOC) emissions and may be regulated under state or local requirements. State or local permits may be required if the site is not a site being remediated under CERCLA authorities. Emissions from the STC treatment process should be monitored, as necessary, to ensure compliance with applicable regulations or permit conditions.

3.8.7 Atomic Energy Act (AEA)

Remedial project managers or facility managers considering use of the STC immobilization technology may need to comply with regulations under the Atomic Energy Act (AEA) if raw waste contains materials defined as source, special, or byproduct nuclear materials. Regulations under 10 CFR part 20 require monitoring of radioactive exposure to individuals, marking of radioactive areas, labelling of radioactive materials, and disposal and recordkeeping requirements. Regulations under 10 CFR part 30 detail Nuclear Regulatory Commission (NRC) licensing requirements for the handling of radioactive materials. Specific licensing requirements for source materials are found under 10 CFR part 40. A license may also be required, under 10 CFR part 61, for the land disposal of certain radioactive wastes. The management of special nuclear materials may also require a license under the provisions of 10 CFR part 70.

Additional requirements may be applicable to the treatment of radioactive wastes at U.S. Department of Energy (DOE) facilities. The DOE issues internal orders to their individual facilities; these orders have the same weight as

regulations at these facilities. These DOE orders address exposure limits for the public, concentrations of radioactivity in soil and water, and management of radioactive wastes.

EPA also has developed standards for the management of radioactive materials under the AEA. Forty CFR part 191 contains requirements for the management and disposal of high-level and transuranic wastes. Regulations for cleanup, control, and waste disposal at uranium and thorium mill tailing sites are found in 40 CFR part 192.

3.8.8 Occupational Safety and Health Act

The Occupational Safety and Health Administration (OSHA) administers standards for the protection of workers from exposure to hazardous chemicals; certain chemicals used in STC's reagent are classified as hazardous chemicals. OSHA regulations applicable to sites where the STC technology is used may include a requirement to develop a written hazard communication program (HCP) under 29 CFR 1910.1200. The HCP requires that remedial project managers or facility managers institute a program to train employees on the hazards of chemicals on site, and requires that Material Safety Data Sheets (MSDS) be available to employees.

OSHA regulations require a variety of actions for worker protection in 29 CFR parts 1900 to 1926. Section 1910.120 requires that persons involved in work at hazardous waste sites (defined as RCRA-permitted and interim status facilities, RCRA corrective action sites, and sites where removal and remedial actions are conducted under CERCLA authorities) undergo a 40-hour health and safety training course and medical surveillance. The training and medical surveillance applies to all persons involved in the STC treatment process, as discussed previously. Regulations in 40 CFR 1910.120 also require the remedial project manager or facility manager to prepare a site health and safety plan, provide PPE for employees, perform air monitoring at the site, and develop decontamination procedures.

Section 4.0

Economic Analysis

One of the goals of SITE is to develop reliable cost data for unique and commercially available hazardous waste treatment technologies. The purpose of this section is to provide information that will allow the remedial project manager or facility manager to develop site-specific costs associated with the use of the STC immobilization technology.

A cost analysis of the STC immobilization technology to treat 15,000 cubic yards of contaminated soil was evaluated using two sizes of mixers (5 and 15 cubic yards) and two different mixing times (1/2 hour and 1 hour) per batch. This analysis revealed a range of costs from $190 to $330 per cubic yard of raw waste depending on the size of the mixer and the duration of mixing. Supplies and consumables were the largest cost in the demonstration, ranging from 47 to 81 percent of the total cost. The reagent cost to treat a cubic yard of waste ranged from $80 to $153 depending on the initial total organic content of the waste. Processing costs ranged from approximately $40 to $175 per cubic yard of waste. Labor costs (9 to 30 percent of the total cost) and analytical expenses (4 to 12 percent of the total cost) were also significant. This section describes the assumptions made and procedures used in determining the technology costs.

4.1 Assumptions

The major assumptions used to evaluate the cost of the STC immobilization technology are based on information provided by STC, or from the actual costs incurred in conducting the SITE demonstration. Certain assumptions were made to account for variable site and waste parameters as well as the nonrepresentative nature of the cost of the demonstration on a waste-unit basis. Some of the assumptions will undoubtedly have to be refined to reflect site-specific conditions.

4.1.1 Waste Volume and Site Size

For the purposes of this analysis, the waste volume is assumed to be 15,000 cubic yards (approximately 18,800 tons) of contaminated soils. It is also assumed that contamination on average extends to a depth of 3 feet from the surface and covers an area of 3 acres (130,680 square feet).

4.1.2 Major Technology Design and Performance Factors

For the purpose of this analysis, it was assumed that the STC immobilization technology is a batch operation conducted in mixers designed to treat either 5 cubic yards or 15 cubic yards of contaminated soils per batch. This analysis was conducted for both mixer capacities using mixing times of one-half hour per batch and one hour per batch; allowing 5 minutes to load contaminated soils and reagents per batch, and 5 minutes to unload the treated wastes. The mixing time of 1/2 hour represents an optimistic assessment that the entire mixing operation for a batch will be completed in 1/2 hour. The 1-hour mixing time represents a more realistic estimate of the time needed for the entire mixing operation per batch. It was also assumed that the mixer will be operated 5 days per week for 8 hours per day. Table 4-1 shows the resulting throughputs and project duration times to remediate the 15,000 cubic-yard site.

4.1.3 Costs Sensitive to Specific Waste/Site Conditions

The cost of the STC treatment process may be affected by variations in waste type or site conditions. In general, the longer it takes to prepare wastes for mixing, the more expensive the STC process becomes. Factors that may increase the cost include raw waste pretreatment

Table 4-1. STC Technology Design and Performance Factors

Option	Mixer Capacity (yd^3)	Mixing Time (hr)	Throughput (yd^3/week)	Duration (months)
1	5	1.0	200	18
2	5	0.5	400	9
3	15	1.0	600	6
4	15	0.5	1,200	3

requirements (e.g., screening and size reduction), difficulty of excavation for on site actions, distance from the raw waste to the mixer, and availability of utilities. For the purposes of this analysis, however, it has been assumed that mixing accounts for the vast majority of time spent during the STC treatment process, and that the time spent preparing for the mixing process is negligible. (That is, preparing for treatment processing will be conducted while other batches are being mixed.)

4.1.4 Financial Assumptions

For the purposes of this analysis, it is assumed that financial factors (such as depreciation on non-capital equipment, interest rates, and nonprocess utility costs) will have a negligible effect on total treatment costs. This assumption is based on the following:

- The STC mixer will likely have little or no salvage value at the end of its life cycle.
- Depreciation of auxiliary support equipment (backhoes and forklifts) will be included in the cost of renting.
- Depreciation of purchased non-capital equipment will be negligible compared to the full cost of the remediation.
- Compared to total site remediation costs, the loss of present value for working capital and contingency costs will be negligible. Therefore, interest rates will not be addressed.

4.2 Itemized Costs

Table 4-2 compares the cost estimates for the STC immobilization technology, using the four options described in Section 4.1.2. The itemized costs include treatment costs only, and are further described below and summarized in Table 4-3 which follows Section 4.2.9. Nontreatment costs including permitting and regulatory costs, performance bonds, insurance, and transport or disposal costs for residuals, PPE, and the treated waste are not included in cost estimates for the STC technology.

4.2.1 Site Preparation Costs

Site preparation costs include site design, surveys, legal searches, access rights, preparation for support facilities and auxiliary equipment and other site-related costs. These preparation costs, exclusive of site development, are assumed to equal 500 staff hours at $50/hour.

4.2.2 Equipment Costs

Equipment costs are divided into two categories: (1) major equipment costs and (2) auxiliary equipment costs. These costs are discussed in the following subsections.

4.2.2.1 Major Equipment Costs

According to STC, the capital cost of a 5-cubic-yard capacity mixer is $50,000 and the cost of a 15-cubic-yard mixer is $150,000. Using straight-line depreciation and assuming a 3-year life cycle, a straight-line depreciation of $16,667 per year for the 5-cubic-yard mixer and $50,000 per year for the 15-cubic-yard mixer is assumed for purposes of this analysis.

Table 4-2. STC Technology Cost Comparison

Cost Items	Options			
	1	2	3	4
Site preparation	$25,000	$25,000	$25,000	$25,000
Equipment	$365,500	$182,750	$138,500	$69,250
Start-Up	$51,800	$51,800	$51,800	$51,800
Supplies and Consumables	$2,298,375	$2,298,375	$2,298,375	$2,298,375
Labor	$1,479,820	$749,684	$496,260	$257,904
Utilities	$86,250	$48,450	$37,500	$24,317
Analytical	$587,813	$297,825	$195,938	$101,888
Maintenance	$7,500	$3,750	$7,500	$3,750
Site Demobilization	$11,250	$11,250	$11,250	$11,250
Total Cost	$4,913,308	$3,668,884	$3,262,123	$2,843,534

4.2.2.2 Auxiliary Equipment Costs

Auxiliary equipment includes such items as a support trailer or decontamination equipment that do not fall under the category of capital equipment costs. For example, although a backhoe is considered a major equipment item, it will not be considered a piece of capital equipment for this analysis.

Auxiliary equipment items may be divided into two categories: rental and purchased equipment. Because of the high cost of purchasing and transporting construction equipment, it will be assumed that this equipment is rented locally, near the site. Based on previous SITE demonstrations, the following rental equipment costs are assumed:

- Site trailer $400/month
- Earth-moving equipment (backhoe and loader) $5,325/month
- Wastewater tank $300/month
- Forklift $1,950/month
- Tank truck $2,000/month
- Scale $1,200/month

Purchased equipment includes miscellaneous expendable materials (such as 55-gallon drums), and equipment that would be cheaper to buy than to rent. For instance, a steam cleaner, electric generator, and all necessary decontamination supplies (including fuel to run the generator) may be purchased for $6,500. The life cycles of the generator and steam cleaner are assumed to be 1 year; for Option 1, it would be necessary to buy these items twice. It is assumed that this equipment will be used on other projects during its life cycle. Auxiliary purchased equipment costs are as follows:

- Miscellaneous equipment (Dumpster, sludge pumps, plastic sheets, 55-gallon drums) $3,200/month
- Personal protective equipment (Disposable boots, gloves, protective clothing, etc.) $4,000/month
- Decontamination equipment (Steam cleaner, generator, fluids) $6,500/year

4.2.3 Startup Costs

The startup cost, including moving all equipment to the site, on-site mobilization, equipment setup, and preliminary chemical and leaching tests of raw waste, is estimated to be $51,800. Of this amount, $46,800 is for preliminary analytical costs including TCLP and TWA.

4.2.4 Supplies and Consumables

The cost for materials is as follows:

- P4 Reagent $600/ton
- P27 Reagent $225/ton

An average of 270 lbs of P4 Reagent and 642 lbs of P27 Reagent were used for every cubic yard of waste processed during the STC demonstration. This corresponds to a total cost of $2,298,375 for reagents used in the demonstration to remediate a 15,000 cubic-yard site. However, because the waste treated during the STC demonstration contained high organic concentrations (e.g., pentachlorophenol), greater quantities of the costlier P4 Reagent were required. According to STC, wastes with negligible organic concentrations (i.e., less than 500 ppm total organics), may require as little as 25 lbs of P4 Reagent for every cubic yard of raw waste treated; this would result in a total cost of $1,195,875 for reagents.

In addition, it is assumed that a 3-month supply of consumables and maintenance materials represents 10 percent of the cost of maintenance or 1 percent of the cost of major equipment ($50,000) per quarter year.

4.2.5 Labor

Based on the SITE demonstration conducted using STC's immobilization technology, eight people from STC per day are assumed to be required to accomplish the remedial action: two to operate the treatment process equipment; five to provide support in the field (such as waste collection); and one to provide off-site support such as data tabulation, reporting and administrative requirements. The two treatment process personnel include a process operator and coordinator. Field support personnel will operate soil-moving equipment (backhoe and forklift), coordinate site health and safety, and collect samples. This analysis assumes that the seven process and field support personnel will receive a per diem in addition to regular compensation. Off-site support personnel receive no per diem. Because it will take an estimated 3 to 18 months to remediate a 15,000-cubic-yard site, the job may involve local hires to reduce transportation costs. This analysis allows for round trips home (one per month) for the seven on-site staff, including the initial and final travel to and from the site.

As described above, eight people per day are required for the remediation. Labor costs are based on a 40-hour week and are assumed to be $40 per hour, including overhead and fringe benefits. In addition, seven of the eight people will receive a per diem of $80 per day to cover the costs of meals and lodging. Since STC envisions that its on-site people will be housed near the site, this per diem will apply for 28 days each month. Each on-site person will be allowed one weekend of paid "home leave" per month, costing $500 in transportation per on-site person.

An after-hours security service is assumed to cost $21 per hour for 108 hours per week (12 hours per weeknight plus the weekend). Health and safety training costs incurred by STC are not included in this cost estimate. Process and field support training, however, is assumed to be of 16 hours duration per field staff.

4.2.6 Utilities

Water is used in the waste treatment process and for decontamination at rates ranging from approximately 30,000 to 154,000 gallons per week depending on the daily throughput as indicated in Options 1 through 4, and assuming from the STC SITE demonstration that water equal to 42 percent of the raw waste is added in the process. Approximately 5,000 gal/wk are assumed necessary for decontamination. Total water usage may vary by as much as 25,000 gal/wk as a result of site and waste variations, specifically moisture content of the raw waste. The cost of water brought to the site in trucks is assumed by STC to be $5 per thousand gallons.

Diesel fuel, approximately 25 gallons per hour, is needed to run the STC process, using the 5-cubic-yard mixer, as well as supporting equipment. Fuel costs (at $1.00/gal, 25 gal/hr) amount to $25.00/hour or $1,000/week,

assuming continuous operation 8 hours/day, 5 days a week. Total fuel costs using the 15-cubic-yard mixer are estimated to be approximately $27.50/hour or $1,100/week.

The cost of telephone and electricity is assumed to be negligible. The cost of these nonfuel utilities is not likely to average more than $5 per day after mobilization depending on climate. (Electricity for the steam cleaner is assumed to be provided by a portable generator run on diesel fuel, and is included in the diesel fuel cost).

4.2.7 Analytical Costs

There are two phases of sampling involved with the STC solidification/stabilization treatment process. The first phase of sampling is of the raw waste using TCLP results to determine if the waste is classified as a hazardous waste. The second phase involves sampling the treated waste. For this phase, it is assumed that three tests will be conducted on the treated waste: Toxicity Characteristic Leaching Procedure (TCLP), total waste analysis (TWA), and analysis for unconfined compressive strength (UCS). The TCLP analysis will be performed to determine if the treated waste is hazardous, and also to evaluate the effectiveness of treatment with respect to inorganics as required by the land disposal restrictions under RCRA. Likewise, TWA results will be used to assess the performance of the technology with respect to organics as required by the land disposal restrictions. Finally, UCS testing will be used to evaluate the structural integrity of the treated waste. Costs for data tabulation and sampling personnel have been included as labor costs.

This analysis assumes that one raw waste sample will be collected every other day. Normally, a full TCLP scan for metals, volatile organic compounds, and semivolatile organic compounds would cost approximately $1,100 per sample. However, an alternative "targeted" analysis for site-specific hazardous constituents of concern is assumed to be $300 per sample. In addition, quality assurance/quality control (QA/QC) samples will be collected; for the purpose of this analysis; the analytical cost of these samples is assumed to equal 25 percent of the total cost of the original analysis.

For sampling of treated waste, it is assumed that 5 percent of the batches will be sampled. Since the throughput rate for the process is 40 batches per week (Options 1 and 3) or 80 batches per week (Options 2 and 4), two treated waste samples will be collected per week for Options 1 and 3, and four treated waste samples will be collected per week for Options 2 and 4. As with the raw waste, the costs for a targeted TCLP analysis of the treated waste is assumed to be $300 per sample. The costs for TWA of metals is assumed to be $110 per sample. The cost for testing the treated waste for UCS is assumed to be $50 per sample. As with the raw waste, the costs for QA/QC sampling are assumed to equal 25 percent of the total cost of the original analysis.

4.2.8 Maintenance Costs

Maintenance costs, including repair and replacement costs, are assumed to be 10 percent of annual major equipment costs. The cost of major equipment (i.e., the mixer) is assumed to be $50,000 for Options 1 and 2, and $150,000 for Options 3 and 4.

4.2.9 Site Demobilization

The cost for site demobilization includes labor costs for final decontamination and removal of equipment, site cleanup and restoration, as well as any necessary run-on/run-off or erosion control measures. Disposal costs for residuals, equipment rinsate and decontamination solution, and PPE are considered nontreatment costs and are not included as site demobilization costs.

Table 4-3. Summary of Itemized Costs

Option 1 (18 months)		
Site Preparation		
	Subtotal	$25,000
Equipment		
Major Equipment		
Mixer ($50,000/36 mo)(18 mo)	$25,000	
Auxiliary Equipment		
Site Trailer ($400/mo)(18 mo)	7,200	
Backhoe & Loader ($5,325/mo)(18 mo)	95,850	
Wastewater Tank ($300/mo)(18 mo)	5,400	
Forklift ($1,950/mo)(18 mo)	35,100	
Tank Truck ($2,000/mo)(18 mo)	36,000	
Scale ($1,200/mo)(18 mo)	21,600	
Miscellaneous Equipment (Dumpster, pumps, plastic sheeting, 55-gallon drums)($3,200/mo)(18 mo)	57,600	
Personal protective Equipment Disposable boots, gloves, protective clothing, etc.) ($4,000/mo)(18 mo)	72,000	
Decontamination Equipment (steam cleaner, generator, fluids) ($6,500/12 mo)(18 mo)	9,750	
	Subtotal	$365,500
Startup		
Miscellaneous Mobilization	$5,000	
Preliminary Analytical		
TWA (24 samples)($1,200/sample)	28,800	
TCLP (24 samples)($750/sample)	18,000	
	Subtotal	$51,800
Supplies and Consumables		
P4 Reagent (2,025 tons)($600/ton)	$1,215,000	
P27 Reagent (4,815 tons)($225/ton)	1,083,375	
	Subtotal	$2,298,375

Table 4-3. Summary of Itemized Costs (Continued)

Labor		
Process Operators (2)($40/hr)(40 hr/wk)(75 wk)	$240,000	
Field Support (5)($40/hr)(40 hr/wk)(75 wk)	600,000	
Off-Site Support (1)($40/hr)(40 hr/wk)(75 wk)	120,000	
Security (1)($21/hr)(108 hr/wk)(75 wk)	170,100	
Per Diem (7)($80/day)(28 day/mo)(18 mo)	282,240	
Home Leave (7)($500/mo)(18 mo)	63,000	
Training (7)($40/hr)(16 hr)	4,480	
Subtotal		$1,479,820
Utilities		
Fuel ($1/gal)(1,000 gal/wk)(75 wk)	$75,000	
Water ($5/1,000 gal)(30,000 gal/wk)(75 wk)	11,250	
Subtotal		$86,250
Analytical		
Pretreatment		
(TCLP) (2.5 samples/wk)($300/sample)(75 wk)	$56,250	
Posttreatment		
(TCLP) (12 samples/wk)($300/sample)(75 wk)	270,000	
(TWA) (12 samples/wk)($110/sample)(75 wk)	99,000	
(UCS) (12 samples/wk)($50/sample)(75 wk)	45,000	
QA/QC ($470,250)(0.25)	117,563	
Subtotal		$587,813
Maintenance		
($5,000/yr)(1.5 yr)	$ 7,500	
Subtotal		$7,500
Site Demobilization		
Labor (225 hr)($50/hr)	$ 11,250	
Subtotal		$ 11,250
Total (Option 1)		$4,913,308

Table 4-3. Summary of Itemized Costs (Continued)

Option 2 (9 months)		
Site Preparation		
Subtotal		$25,000
Equipment		
Major Equipment		
Mixer ($50,000/36 mo)(9 mo)	$12,500	
Auxiliary Equipment		
Site Trailer ($400/mo)(9 mo)	3,600	
Backhoe & Loader ($5,325/mo)(9 mo)	47,925	
Wastewater Tank ($300/mo)(9 mo)	2,700	
Forklift ($1,950/mo)(9 mo)	17,550	
Tank Truck ($2,000/mo)(9 mo)	18,000	
Scale ($1,200/mo)(9 mo)	10,800	
Miscellaneous Equipment (Dumpster, pumps, plastic sheeting, 55-gallon drums)($3,200/mo)(9 mo)	28,800	
Personal protective Equipment Disposable boots, gloves, protective clothing, etc.) ($4,000/mo)(9 mo)	36,000	
Decontamination Equipment (steam cleaner, generator, fluids) ($6,500/12 mo)(9 mo)	4,875	
Subtotal		$182,750
Startup		
Miscellaneous Mobilization	$5,000	
Preliminary Analytical		
TWA (24 samples)($1,200/sample)	28,800	
TCLP (24 samples)($750/sample)	18,000	
Subtotal		$51,800
Supplies and Consumables		
P4 Reagent (2,025 tons)($600/ton)	$1,215,000	
P27 Reagent (4,815 tons)($225/ton)	1,083,375	
Subtotal		$2,298,375

Table 4-3. Summary of Itemized Costs (Continued)

Labor		
Process Operators (2)($40/hr)(40 hr/wk)(38 wk)	$121,600	
Field Support (5)($40/hr)(40 hr/wk)(38 wk)	304,000	
Off-Site Support (1)($40/hr)(40 hr/wk)(38 wk)	60,800	
Security (1)($21/hr)(108 hr/wk)(38 wk)	86,184	
Per Diem (7)($80/day)(28 day/mo)(9 mo)	141,120	
Home Leave (7)($500/mo)(9 mo)	31,500	
Training (7)($40/hr)(16 hr)	4,480	
Subtotal		$749,684
Utilities		
Fuel ($1/gal)(1,000 gal/wk)(38 wk)	$38,000	
Water ($5/1,000 gal)(55,000 gal/wk)(38 wk)	10,450	
Subtotal		$48,450
Analytical		
Pretreatment		
(TCLP) (2.5 samples/wk)($300/sample)(38 wk)	$28,500	
Posttreatment		
(TCLP) (12 samples/wk)($300/sample)(38 wk)	136,800	
(TWA) (12 samples/wk)($110/sample)(38 wk)	50,160	
(UCS) (12 samples/wk)($50/sample)(38 wk)	22,800	
QA/QC ($238,260)(0.25)	59,565	
Subtotal		$297,825
Maintenance		
($5,000/yr)(0.75 yr)	$ 3,750	
Subtotal		$3,750
Site Demobilization		
Labor (225 hr)($50/hr)	$ 11,250	
Subtotal		$ 11,250
Total (Option 2)		$3,668,884

Table 4-3. Summary of Itemized Costs (Continued)

Option 3 (6 months)		
Site Preparation		
Subtotal		$25,000
Equipment		
Major Equipment		
Mixer ($150,000/36 mo)(6 mo)	$25,000	
Auxiliary Equipment		
Site Trailer ($400/mo)(6 mo)	2,400	
Backhoe & Loader ($5,325/mo)(6 mo)	31,950	
Wastewater Tank ($300/mo)(6 mo)	1,800	
Forklift ($1,950/mo)(6 mo)	11,700	
Tank Truck ($2,000/mo)(6 mo)	12,000	
Scale ($1,200/mo)(6 mo)	7,200	
Miscellaneous Equipment (Dumpster, pumps, plastic sheeting, 55-gallon drums)($3,200/mo)(6 mo)	19,200	
Personal protective Equipment Disposable boots, gloves, protective clothing, etc.) ($4,000/mo)(6 mo)	24,000	
Decontamination Equipment (steam cleaner, generator, fluids) ($6,500/12 mo)(6 mo)	3,250	
Subtotal		$138,500
Startup		
Miscellaneous Mobilization	$5,000	
Preliminary Analytical		
TWA (24 samples)($1,200/sample)	28,800	
TCLP (24 samples)($750/sample)	18,000	
Subtotal		$51,800
Supplies and Consumables		
P4 Reagent (2,025 tons)($600/ton)	$1,215,000	
P27 Reagent (4,815 tons)($225/ton)	1,083,375	
Subtotal		$2,298,375

Table 4-3. Summary of Itemized Costs (Continued)

Labor			
Process Operators (2)($40/hr)(40 hr/wk)(25 wk)		$80,000	
Field Support (5)($40/hr)(40 hr/wk)(25 wk)		200,000	
Off-Site Support (1)($40/hr)(40 hr/wk)(25 wk)		40,000	
Security (1)($21/hr)(108 hr/wk)(25 wk)		56,700	
Per Diem (7)($80/day)(28 day/mo)(6 mo)		94,080	
Home Leave (7)($500/mo)(6 mo)		21,000	
Training (7)($40/hr)(16 hr)		4,480	
	Subtotal		$496,260
Utilities			
Fuel ($1/gal)(1,000 gal/wk)(25 wk)		$27,500	
Water ($5/1,000 gal)(80,000 gal/wk)(25 wk)		10,000	
	Subtotal		$37,500
Analytical			
Pretreatment		$18,750	
(TCLP) (2.5 samples/wk)($300/sample)(25 wk)			
Posttreatment		90,000	
(TCLP) (12 samples/wk)($300/sample)(25 wk)		33,000	
(TWA) (12 samples/wk)($110/sample)(25 wk)		15,000	
(UCS) (12 samples/wk)($50/sample)(25 wk)			
		39,188	
QA/QC ($470,250)(0.25)			
	Subtotal		$195,938
Maintenance			
($15,000/yr)(0.5 yr)		$ 7,500	
	Subtotal		$7,500
Site Demobilization			
Labor (225 hr)($50/hr)		$ 11,250	
	Subtotal		$ 11,250
	Total (Option 3)		$3,262,123

Table 4-3. Summary of Itemized Costs (Continued)

Option 4 (3 months)		
Site Preparation		
Subtotal		$25,000
Equipment		
Major Equipment		
Mixer ($150,000/36 mo)(3 mo)	$12,500	
Auxiliary Equipment		
Site Trailer ($400/mo)(3 mo)	1,200	
Backhoe & Loader ($5,325/mo)(3 mo)	15,975	
Wastewater Tank ($300/mo)(3 mo)	900	
Forklift ($1,950/mo)(3 mo)	5,850	
Tank Truck ($2,000/mo)(3 mo)	6,000	
Scale ($1,200/mo)(3 mo)	3,600	
Miscellaneous Equipment (Dumpster, pumps, plastic sheeting, 55-gallon drums)($3,200/mo)(3 mo)	9,600	
Personal Protective Equipment Disposable boots, gloves, protective clothing, etc.) ($4,000/mo)(3 mo)	12,000	
Decontamination Equipment (steam cleaner, generator, fluids) ($6,500/12 mo)(3 mo)	1,625	
Subtotal		$69,250
Startup		
Miscellaneous Mobilization	$5,000	
Preliminary Analytical		
TWA (24 samples)($1,200/sample)	28,800	
TCLP (24 samples)($750/sample)	18,000	
Subtotal		$51,800
Supplies and Consumables		
P4 Reagent (2,025 tons)($600/ton)	$1,215,000	
P27 Reagent (4,815 tons)($225/ton)	1,083,375	
Subtotal		$2,298,375

Table 4-3. Summary of Itemized Costs (Continued)

Labor			
Process Operators (2)($40/hr)(40 hr/wk)(13 wk)		$41,600	
Field Support (5)($40/hr)(40 hr/wk)(13 wk)		104,000	
Off-Site Support (1)($40/hr)(40 hr/wk)(13 wk)		20,800	
Security (1)($21/hr)(108 hr/wk)(13 wk)		29,484	
Per Diem (7)($80/day)(28 day/mo)(3 mo)		47,040	
Home Leave (7)($500/mo)(3 mo)		10,500	
Training (7)($40/hr)(16 hr)		4,480	
	Subtotal		$257,904
Utilities			
Fuel ($1/gal)(1,000 gal/wk)(13 wk)		$14,300	
Water ($5/1,000 gal)(154,000 gal/wk)(13 wk)		10,017	
	Subtotal		$24,317
Analytical			
Pretreatment		$9,750	
(TCLP) (2.5 samples/wk)($300/sample)(13 wk)			
Posttreatment		46,800	
(TCLP) (12 samples/wk)($300/sample)(13 wk)		17,160	
(TWA) (12 samples/wk)($110/sample)(13 wk)		7,800	
(UCS) (12 samples/wk)($50/sample)(13 wk)			
		20,378	
QA/QC ($470,250)(0.25)			
	Subtotal		$101,888
Maintenance			
($15,000/yr)(0.25 yr)		$ 3,750	
	Subtotal		$3,750
Site Demobilization			
Labor (225 hr)($50/hr)		$ 11,250	
	Subtotal		$ 11,250
	Total (Option 4)		$2,843,534

Table 4-3. Summary of Itemized Costs (Continued)

Note: These figures correspond to the following approximate costs per cubic yard of raw waste, for each option, assuming on-site in-place disposal:

- Option 1 $330
- Option 2 $245
- Option 3 $220
- Option 4 $190

Off-site transport and disposal could significantly increase these costs.

Additionally, the lower the organic concentrations in the raw waste, the less P4 Reagent is needed. If the raw waste contains negligible organic concentrations (less than 500 ppm total organics), as little as 1 percent by weight P4 Reagent would be needed. This would result in the following costs per cubic yard of raw waste for each option:

- Option 1 $255
- Option 2 $170
- Option 3 $145
- Option 4 $120

Section 5.0

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Appendix A

Vendor's Claims for the Technology

Appendix A

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Appendix A

Vendor's Claims for the Technology

Introduction

Traditionally, organic sludges and contaminated soils have been solidified through the use of lime, kiln dust, fly ash, and portland cement. These low-technology methods have a common approach: the organic waste being treated is detained in a solidified mass without being truly stabilized insofar as leaching is concerned. In addition, these traditional approaches require voluminous amounts of pozzolonic materials in order to increase the strength of the treated material for its ultimate use in landfills. The end result yields a treated waste product that is 2 to 3 times larger than the original waste volume, thereby creating high waste mixing, transporting, and disposal costs. These costs substantially reduce the benefits of utilizing inexpensive pozzolans.

During the last 10 years, various innovative immobilization technologies have been developed with the intention of significantly reducing the extractable concentration of organic and/or inorganic constituents, including difficult-to-stabilize inorganic contaminants such as arsenic, hydrogen cyanide, and hexavalent chromium. These innovative immobilization technologies have involved the use of surface-modified agents (such as clays), surfactants, and other reagents (such as silicates) to stabilize waste constituents in conjunction with solidification.

The STC technology for contaminant immobilization involves stabilization of the waste's organic and inorganic components to decrease leachability and lower the interference of the component contaminants with the solidification/stabilization matrix. This immobilization is followed by bonding and microencapsulation of the waste in a solid silicate matrix in order to yield adequate physical strength and further reduce leachability. The final immobilization treatment steps are accomplished by ambient temperature mixing of STC treatment reagents, utilized in either dry form or as a slurry.

The STC immobilization technology has been used, in conjunction with the proper materials handling equipment, for various soils and sludges to remediate complex hazardous waste sites. This immobilization/encapsulation process reduces leachability of hazardous materials in conformance with applicable federal, state, and local regulations (STC, 1988). A description of the STC immobilization technology which utilizes calcium-aluminum-silicate compounds for the treatment of organic as well as inorganic hazardous wastes, sludges, and soils, and its attendant applications is presented in the following section.

STC's Immobilization Technology

The STC immobilization technology is a solidification/stabilization treatment process that utilizes a proprietary product (FMS silicate) developed by STC to selectively adsorb organics in amounts up to 20 times its weight. When combined with a cementitious material, the reagents selectively adsorb organic and inorganic contaminants and yield a high-strength monolith. The resulting rock-like materials have reportedly passed federal and state regulatory threshold levels for TCLP and CALWET leachate tests, respectively. Additionally, there have been demonstrated indications that the resultant leachability decreases with age.

Two distinct groups of STC proprietary reagents, utilizing silicate-based formulations, have been developed. One group of reagents is used for treating inorganic-contaminated wastes; another group of reagents has been utilized in

the treatment of organic wastes. The stabilization of the organic waste to prevent leaching occurs as a result of applying the reagent in a single step that initiates three simultaneous chemical reactions. The organic compounds in the waste are sequestered by organically surface-modified alumino-silicate minerals. When this compound is mixed with organic waste, it bonds the organic compounds into the layers of the organically surface-modified alumino-silicate compound by a partitioning reaction. The surface-modified layers in the compound can ultimately adsorb as much as 20 times their own weight in organic waste, and the adsorbed organic waste cannot be physically squeezed out of the layered silicate structure.

Soil stabilization of organic- and inorganic-contaminated wastes occurs as a result of forming organophilic silicate compounds that react with the contaminants in the waste and immobilizing them to prevent their leaching. This results in a very stable compound analogous to common rock-forming silicate minerals with excellent physical strength and very low leachability. The process is depicted in a flow diagram in Figure A-1.

Applications of the STC Technology

Organic Contaminants

Hazardous wastes in a soil or sludge medium containing organic contaminants such as halogenated, aromatic, and aliphatic hydrocarbons are treated through STC's contaminated soil process. STC claims that the concentration level of the organic contaminants listed above is not relevant to the success of the treatment process since STC's proprietary reagents are adjusted accordingly. It should be noted that STC reagents are not as successful on low-molecular-weight organic contaminants such as alcohols, ketones, and glycols.

Inorganic Contaminants

Hazardous wastes in soils or sludges containing inorganic contaminants such as heavy metals, arsenate, chromate, selenium, fluorides, and cyanides are treated through STC's contaminated soil process, as demonstrated at the SPT site and shown in the various case studies described in Appendix C.

Summary

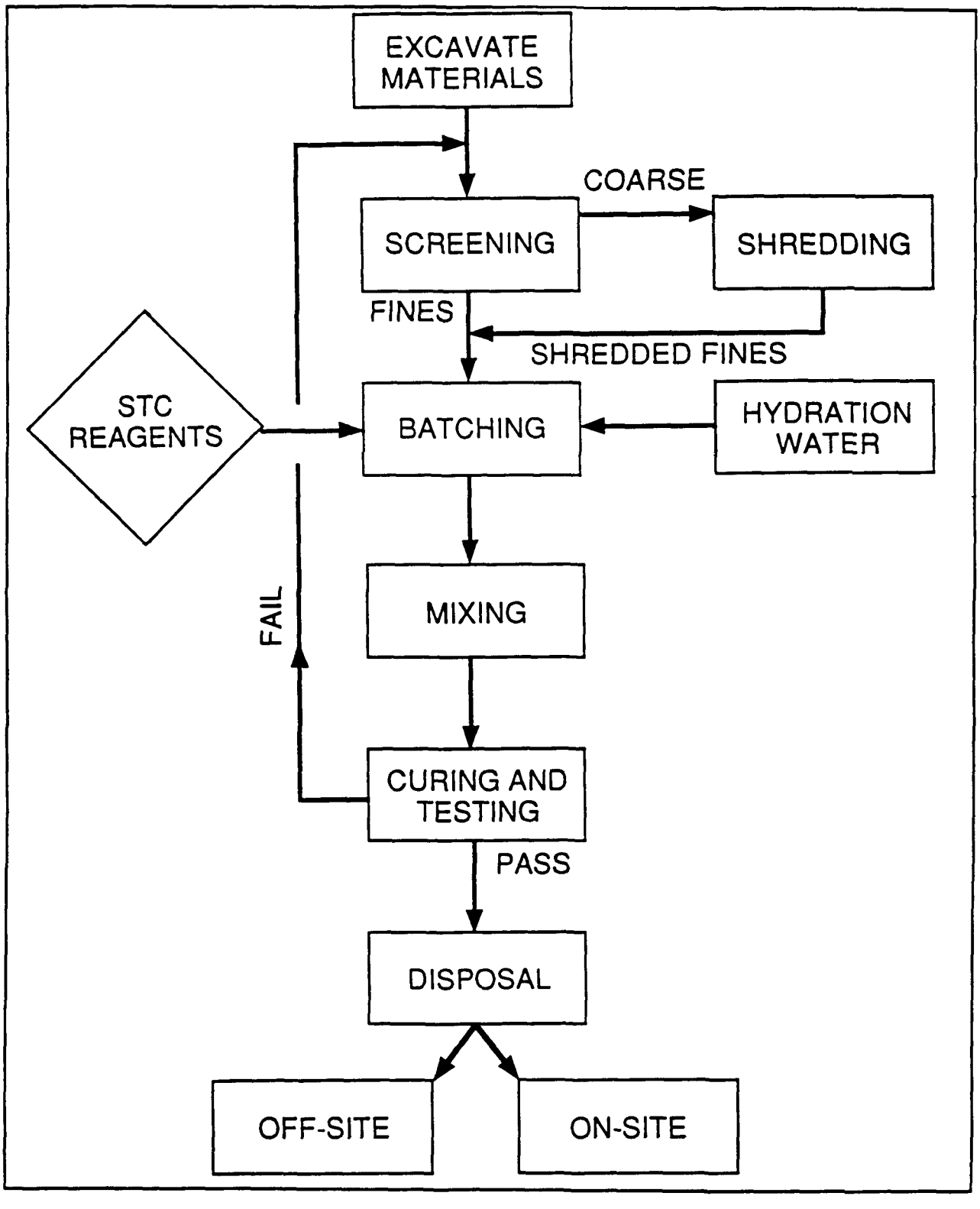
Since 1982 STC has been directly involved in the successful treatment of organic and inorganic hazardous wastes including contaminated soils and sludges. The treatment programs are based on the utilization of a proprietary product developed by STC. This product (FMS Silicate) is an organophilic silicate that selectively adsorbs organics in amounts up to 20 times the weight of FMS Silicate. The STC solidification/stabilization treatment process has been utilized to render characteristic hazardous wastes, contaminated soils, and sludges as nonhazardous. (STC, 1987).

References

STC, 1987. Technology and Services: Cost Effective Solutions to Your Hazardous Waste Management Problems.

STC, 1988. Proposal for U.S. EPA, SITE 003, Organophilic Silicate Processes for Remediation of Both Soil and Water at Complex Hazardous Sites.

Figure A-1 Contaminated Soil Process Flow Diagram



Appendix B

SITE Demonstration Results

Appendix B

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Appendix B

SITE Demonstration Results

Introduction

The overall goal of the Silicate Technology Corporation (STC) demonstration at the Selma Pressure Treating (SPT) site was to evaluate the effectiveness of the STC technology as a long-term remedial measure at Superfund sites and RCRA corrective action sites. The SPT site was selected for the demonstration based on its waste characteristics, the results of treatability testing, and site logistical considerations. STC's technology is designed for sites with mixed organic and inorganic contaminants, including polycyclic aromatic hydrocarbons (PAH) and heavy metals as reported by CDM at the SPT site (CDM, 1988a and b). *The primary objective of this demonstration was to determine if the STC immobilization technology could reduce the potential leachability and mobility of contaminants as measured by TWA for organics and the TCLP for inorganics.* In particular, the principal contaminants for assessing the STC technology were pentachlorophenol (PCP) and arsenic. Additional objectives of this demonstration include the following:

- Determine if the STC technology could reduce the leachability of contaminants as measured by other leaching procedures.
- Determine if the STC technology could reduce leachate concentrations of PCP and metals below applicable regulatory limits to allow for legal disposal as a nonhazardous waste.
- Determine the homogeneity of mixing and structural characteristics of the STC treated waste.
- Determine the volume and density increase of the solidified material due to added reagents.
- Determine if the STC technology could treat contaminated soils to produce a monolithic block that would resist the effects of weathering.
- Determine whether the treated, solidified waste could maintain its structural properties and stabilization effectiveness over a 3-year period.
- Develop capital and operating cost models for the technology that can be used reliably in the Superfund and RCRA decision-making process.

This appendix presents the results of the STC SITE demonstration, in addition to providing background information about the SPT site in Selma, California, and the waste characteristics at this site.

Site Background

The SPT site has been used for chemical treatment of lumber since 1942. The original wood-preserving process consisted of dipping the lumber into a mixture of PCP and oil, and allowing the excess fluid to drip off as the wood dried on open storage racks. In 1965, site operators converted to a pressure-treating process that consisted of two steps: (1) conditioning the lumber to reduce moisture content and increase permeability, and (2) impregnating the wood with chemical preservatives.

Federal and state agencies have been jointly involved in regulatory actions at the site since the 1970s. The California Regional Water Quali-

ty Control Board (CRWQCB) was first to impose discharge standards, monitor water quality, and require the owners to submit operational reports. On January 13, 1981, the following agencies conducted an Uncontrolled Hazardous Waste Site Investigation: EPA's Field Investigation Team (FIT), California Environmental Protection Agency (CEPA), and CRWQCB. SPT filed for bankruptcy on April 13, 1981, and the plant closed its operations in June 1981. On September 4, 1981, CRWQCB issued a Cleanup and Abatement Order to SPT. SPT indicated it could not comply with the Cleanup and Abatement Order; however, an attorney for Selma Leasing Company (the landowner) indicated to CRWQCB that Selma Leasing Company would accept responsibility for the geotechnical investigation portion of the order. In February 1982 Sawmill Properties, Inc., acquired the facility, but stipulated that Selma Leasing Company continue to accept responsibility for the investigations of contamination caused by past operations. Sawmill Properties, Inc., reopened the plant in Summer 1982, as the Selma Treating Company. In August 1983, EPA scored the site at 48.83 using the Hazard Ranking System (HRS). Based on this information, the site was placed on the Superfund National Priorities List (NPL) in September 1983. Following a remedial investigation/feasibility study (RI/FS), a Record of Decision (ROD) was signed on September 24, 1988, and a Pre-Remedial Design Soil Boring Report was completed in June, 1989 (CDM, 1989).

Site Description

The SPT site is located approximately 15 miles southeast of Fresno, California, adjacent to the southern city limits of Selma, California (Figure B-1). The site is situated in the center of the San Joaquin River Valley, an area that contains abundant vineyards. The entire SPT site covers 18 acres; however, the actual wood-treatment area of this site covers only 3 to 4 acres. While zoned for heavy industrial use, the site is located in a transition zone between agricultural, residential, and industrial areas with approximately 12 residences and businesses located within 1/4-mile. The CRWQCB has classified the ground-water resources in the vicinity of the SPT site as a beneficial use, sole-source aquifer. This resource provides the necessary domestic water supply for the surrounding communities and scattered county residences. Surface-water irrigation systems are also supplemented by this ground-water resource.

Site Contamination Characteristics

From 1942 to 1971, wastes from the treatment plant were disposed of in various ways: (1) runoff into drainage ditches and a percolation ditch; (2) drainage into dry wells; (3) spillage on open ground; (4) placement into an unlined pond and a sludge pit; and (5) disposal in an adjacent vineyard (Figure B-2). Known chemical preservatives used at the site include:

- Fluor-chromium-arsenate-phenol (1966 to 1973)
- Woodtox 140 RTU (1974 only)
- Heavy oil penta solution (1977 only)
- LST concentrate (1970 to 1979)
- Copper-8-quinolinoate (1977 to 1980)
- PCP (1970 to present)
- Chromated-copper-arsenate (CCA) (1973 to present)

A contaminated ground-water plume emanating from the site has been identified in addition to pervasive soil contamination beneath the SPT site. The Pre-Remedial Design Soil Boring Report (CDM, 1989) for the site indicates that the primary metal contaminants are arsenic, chromium, and copper. PCP was also reported along with associated degradation and impurity products, including polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans (PCDF), and chlorinated phenols. Hydrocarbon-related constituents were reported at the site and may have resulted from the use of diesel fuel as a carrier for the PCP. The hydrocarbon-related constituents include volatile organic compounds such as benzene, toluene, and xylene, and polycyclic aromatic hydrocarbons (PAH) such as naphthalene and pyrene. Results from the Pre-Remedial Design Soil Boring Report (CDM, 1989) and Final Remedial Investigation Report (CDM, 1988a) confirm that the highest levels of contamination occur in the first 5 feet of the soil material.

Figure B-1. Regional Location Map - SPT Site, Selma, California

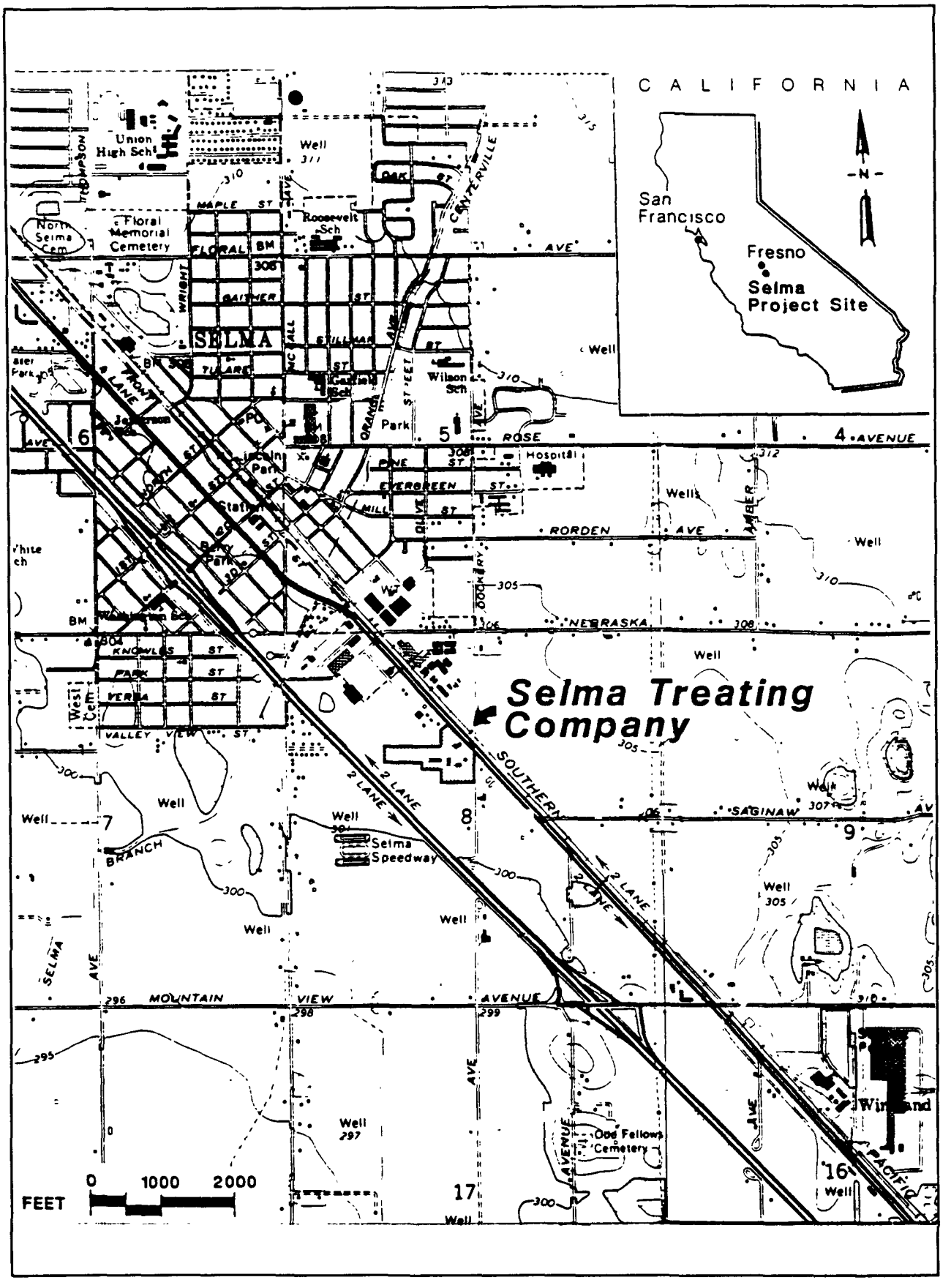
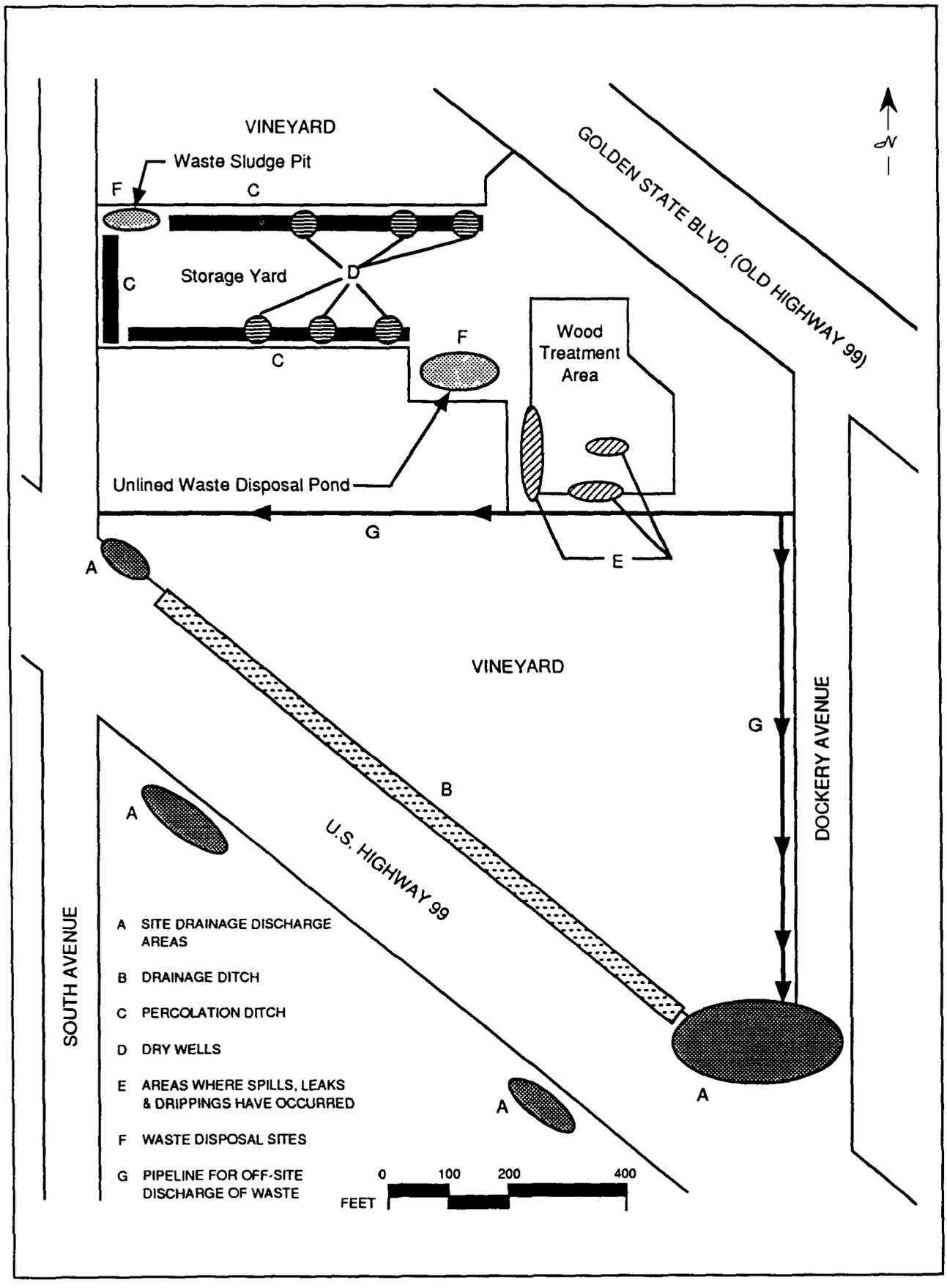


Figure B-2. Areas of Contamination at the SPT Site



SITE Demonstration Procedures

The SITE demonstration was divided into three phases: (1) site preparation; (2) technology demonstration; and (3) site decontamination, demobilization, and waste disposal. These activities and a review of technology and equipment performance during these phases are described below.

Site Preparation

Site preparation began 1 week prior to the treatment technology demonstration. EPA and its contractors established a waste treatment decontamination area, staging and storage areas, a decontamination zone, and a public viewing area as depicted in Figure B-3. The personnel decontamination pad was 6 feet wide, 10 feet long, and 2 feet deep on one end. A layer of 20-mil high-density polyethylene (HDPE) attached to railroad ties was used to line the decontamination pad. A pump was placed in the decontamination pad to provide for the collection of all rinsate resulting from equipment decontamination. Decontamination of construction equipment was conducted on 20-mil HDPE in the waste excavation pit.

On-Site Logistics

To successfully meet the demonstration objectives, the EPA SITE team and STC personnel used the following on-site provisions:

- A 50- by 100-foot compacted soil area for the STC process equipment and temporary accumulation of waste and treatment reagents. The process equipment area was constructed with a plastic liner and berm.

- A 45- by 6-foot gravel and compacted soil area for the office and laboratory trailer. An area appropriate for parking and equipment staging was also provided.

- A 15- by 50-foot area lined with 20-mil HDPE liner to place and store the solidified waste. The treated waste was discharged into cardboard concrete forms mounted on pallets, and placed in the storage area. The storage area was graded in such a way that a low point in the liner existed for collection of any rainwater runoff from the solidified waste.

- A dumpster for containment and disposal of all nonhazardous waste.

- Diesel electric generator to supply 480-volt, 3-phase, 500-amp service for STC process equipment. In addition, standard electric power was provided by a portable generator for the support trailer, equipment, and miscellaneous needs.

- Process and wash water for the treatment unit and decontamination. This water was obtained from the facility's potable water. Approximately 220 gallons of water were required per treated batch.

- A scale for weighing reagents and raw wastes.

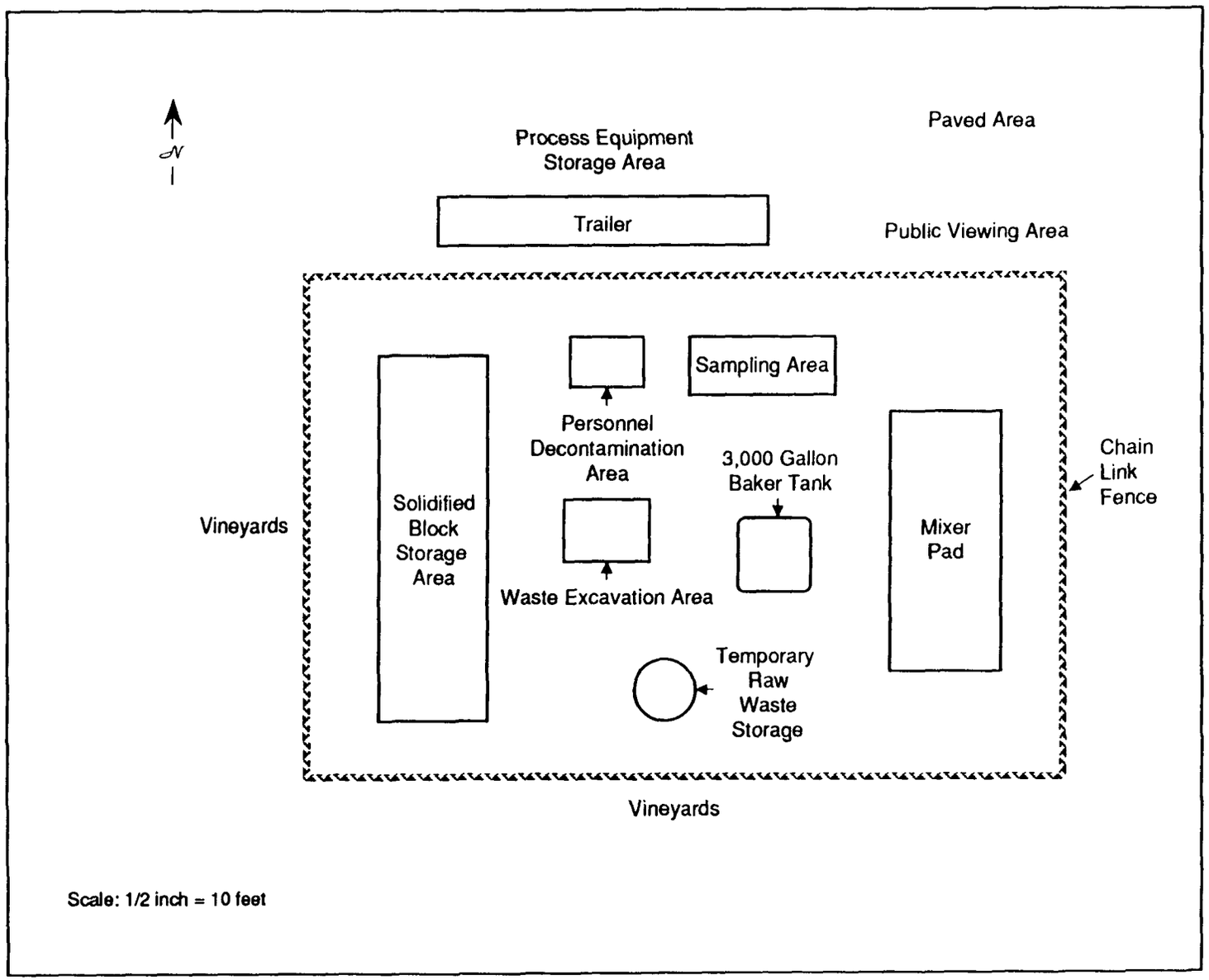
- A heavy equipment decontamination area bermed and lined with 20-mil plastic for cleaning large equipment. This area was also provided with a pump for the collection of wash water.

- A personnel decontamination station adjacent to the equipment decontamination area. The station was supplied with appropriate basins, brushes, water, and soap. This area also included several tables to function as an equipment drop, a first-aid station, and emergency eye-wash facilities.

- A 3,000-gallon Baker wastewater tank used to contain decontamination water.

- A gasoline-powered, high-pressure cleaner to clean the STC process equipment and other heavy equipment.

Figure B-3. SPT SITE Demonstration Layout



- Three 55-gallon drums to contain contaminated clothing, supplies, and other materials that could not be disposed of in the dumpster. These drums were disposed of at appropriate off site facilities.

- A 45-foot office and sampling trailer for EPA, contractor, and STC personnel.

- A portable telephone for ordering supplies, scheduling deliveries, and emergency communications.

- Sanitary facilities for personnel involved with the demonstration.

- A public viewing area for the demonstration.

- A locked chain-linked fence constructed around the work area upon completion of the demonstration. Entry to the SPT property was restricted during the demonstration between 5:00 p.m. and 8:00 a.m.

Technology Demonstration

This section discusses waste collection procedures as well as equipment startup and test run procedures. In addition, operational and equipment problems along with health and safety considerations are addressed.

Collection of Waste Material for Treatment

A backhoe/front-end loader was used to collect contaminated waste material from the unlined waste disposal pond. To ensure that the waste with the highest concentration of contaminants was tested, the first 3 feet of soil material from the disposal pond were used for the demonstration. Therefore, it was necessary to excavate approximately a 300-square-foot area to a depth of 3 feet to provide the total amount of contaminated soil needed for the demonstration. The excavation was lined with a layer of 20-mil HDPE and backfilled with 1 foot of sand overlaid by 1 foot of crushed stone (1-inch diameter) and clean soil at the conclusion of the demonstration.

Contaminated soils from the unlined waste disposal pond were transported directly to the processing area, where temporary storage piles covered by 10-mil HDPE were set up as necessary prior to batch processing. Each batch was thoroughly mixed in a 5-cubic-yard high-intensity batch mixer prior to the addition of STC reagents.

Equipment Startup and Test Runs

Upon completion of the equipment setup, STC conducted a startup and test run to ensure that the equipment was operating properly and that all SITE team members understood the sampling procedures. During this procedure, a small batch of treatment reagents (695 lbs) with clean silica sand (1,972 lbs) instead of waste material was processed. This initial "reagent mixture" constituted a treatment process blank.

Treatment startup began with the transport of approximately 5,000 lbs of raw waste material to the mixer. The contaminated soil was blended in the mixer until STC confirmed the waste was adequately homogenized. Pretreatment grab samples were taken directly from the mixer discharge at three separate intervals and placed into sample containers prior to the addition of treatment reagents. Mixing continued for up to 1 hour following the addition of treatment reagents and water. The treated material was then discharged into three 1-cubic-yard cardboard forms. Samples were collected from the forms immediately after the treated waste was discharged from the mixer. For each batch run, complete records were maintained of pertinent operating parameters including weight of the soil waste, STC reagents, and water added; mixer power; and mixing time (see Table 3-1 of the Application Analysis Report).

Operational Problems

A few operational problems were encountered during the STC SITE demonstration. These operational problems included (1) incomplete mixing of certain wastes (especially during Batch 2) and (2) excessive dust generation from the movement of equipment and site personnel. Both of these operational problems, and responses to these problems, are discussed in detail below.

Certain contaminated soils (the PCP-encrusted "hardpan") treated during the demonstration were not well mixed after treatment; the treated waste contained large (up to 2-inch) inclusions of untreated waste. This problem resulted in the exclusion of Batch 2 from analytical evaluation. The problem was solved in subsequent batches by forcing the raw waste through a series of screens prior to treatment, reducing the raw waste aggregate size to approximately 0.04 to 0.08 inch (1-2 mm) diameter. This pretreatment allowed for adequate mixing to occur; the subsequent batches (i.e., Batches 3 through 5) appeared to be homogeneous mixtures.

The generation of large amounts of contaminated dust from the movement of equipment, supplies, and site personnel caused fouling of the intake to the photoionization device that was used for air monitoring. The dust problem was remedied through the application of water to the site from a water truck. An additional operational problem was the dust cloud created upon initially mixing the dry reagents in the mixer. A portion of the necessary water was added to the homogenized waste before the addition of dry reagents; however, the short amount of time it took to thoroughly wet the dry reagents still resulted in the generation of a dust cloud. Consequently, a tarp was secured over the top of the mixer after adding dry reagents. Although no downwind residents or receptors were affected by the small dust cloud of finely divided dry reagents during the demonstration, slurrying the reagents prior to addition may be desirable for future uses of the technology.

Health and Safety Considerations

The overall hazard rating for the SPT site was moderate as indicated by preliminary analyses, which reported high concentrations of semivolatile organic compounds and toxic heavy metals. Several compounds were suspected carcinogens. Potential routes of exposure during the demonstration were inhalation, ingestion, and skin and eye contact during sample transport, treatment, and collection.

All personnel working at the SPT site had, at a minimum, 40 hours of health and safety training and were under routine medical surveillance. Personnel were required to wear protective equipment appropriate for the activity being performed. A modified Level D protection was recommended; however, personnel working in direct contact with contaminated soils donned Level C protective equipment including a full-face respirator with GMA-H cartridges, Tyvek coveralls, steel-toed leather work boots and rubber booties, hard hat, latex inner gloves, and nitrile outer gloves.

Decontamination, Demobilization, and Waste Disposal

Prior to waste collection activities, all STC equipment that would come in contact with raw waste materials was decontaminated. In addition, all process equipment was decontaminated between batch runs and at the conclusion of the demonstration. A portable high-pressure cleaner was used to decontaminate the equipment. Water and wastes generated from the cleaning of equipment were pumped to a 3,000-gallon Baker wastewater tank and stored on site for subsequent disposal. Personnel decontamination wash water and wastes were collected from wash basins and also placed in this tank for off-site disposal. All sampling equipment was cleaned with a nonphosphate detergent and triple rinsed with distilled water before reuse. The wash water containing soap was drummed and stored on site for disposal.

Once all test runs were completed and equipment decontaminated, all test equipment was demobilized and removed from the SPT site. Decontamination and demobilization took approximately 2 weeks. The demonstration wastes included 1,000 gallons of water and wastes from decontamination, three 55-gallon drums of contaminated clothing and disposable sampling supplies, and a 30-cubic-yard dumpster containing miscellaneous nonhazardous trash. The decontamination wastes, drums, and dumpster wastes were disposed of by EPA and its contractors at appropriate facilities.

The 1-cubic-yard cardboard form containing treated clean sand and 15 similar forms filled with treated wastes were placed on wooden pallets in the western section of the demonstration site. After 28 days, the cardboard forms were removed and disposed. The exposed monoliths of treated waste will be inspected periodically for 3 years. After the 3-year monitoring period ends, EPA will dispose of these wastes according to the cleanup criteria selected for the SPT site and all applicable or

relevant and appropriate requirements.

Review of Treatment Results

This section summarizes the results of analyses for critical analytes as well as noncritical parameters for the STC solidification/stabilization demonstration as delineated in the STC SITE Program Demonstration Quality Assurance Project Plan (QAPjP). This section also evaluates the technology's effectiveness in reducing the mobility and leachability of selected toxic contaminants.

Testing Approach

Preliminary testing at the SPT site indicated that the contaminated areas contained essentially similar contaminants but in varying concentrations (CDM, 1988a and b, and 1989). The highest levels of contaminants were reported from the unlined dry waste disposal pond. Contaminated soils from this area were treated during the demonstration to provide the most severe conditions for determining treatment effectiveness.

The contaminants of regulatory concern at the SPT site were arsenic and PCP which were targeted for treatment during the demonstration. Other non-target contaminants were chromium, copper, nickel, and lead, as well as other semivolatile organic compounds such as phenanthrene, tetrachlorophenol, phenol, and naphthalene. The corresponding critical measurements for the demonstration were TCLP for arsenic (and other inorganic analytes) and TWA for PCP (and other organic analytes). Noncritical measurements included TCLP for organic analytes, and TCLP-Distilled Water and CALWET leach procedures for both organic and inorganic analytes. Additional noncritical measurements for the demonstration included the TCLP-Cage and a modified American Nuclear Society (ANS) 16.1 leach test, analysis for PCDDs and PCDFs, engineering and geotechnical tests, and petrographic examination. In addition, chemical characterization of the raw and treated waste included pH, Eh, loss on ignition, and neutralization potential analyses. Acid neutralization capacity tests originally planned for the raw wastes to determine the buffering capacity could not be completed due to the slightly acidic nature of the raw waste samples. Instead, neutralization potential measurements were conducted on both the raw waste and treated waste samples for comparison purposes.

For critical measurements, six or more field replicate samples of raw and treated waste were collected, depending on data variability as determined in the initial treatability tests from the SPT site. Field replicate samples were analyzed for arsenic, chromium, copper, nickel, lead, and semivolatile organic compounds including PCP. In addition, field replicate geotechnical/engineering samples were collected for unconfined compressive strength, permeability, and petrographic examination, but not for particle size, water content, bulk density, wet/dry, or freeze/thaw testing.

EPA-approved sampling, analytical testing, and quality assurance and quality control (QA/QC) procedures were followed to obtain data of known quality. Details on QA/QC procedures are presented in Volume III of the demonstration plan (U.S. EPA, 1990). A quality assurance review of the demonstration data was performed by Engineering-Science, Inc. Details of this review can be found in the report "Draft Data Summary for the STC SITE Demonstration," ES, November, 1991. In general, the usability of the data generated by Engineering-Science, Inc. Berkeley Laboratory (ESBL) to meet the objectives of the demonstration was not affected by the QA outliers found during validation of the data. Table B-1 summarizes analytical and measurement methods.

Summary of Results for Critical Analytes

Analytical results for arsenic, chromium, copper, and pentachlorophenol (PCP) in waste material treated by STC using the TCLP, TCLP-Distilled Water, and TWA methods of analysis are presented in Table B-2. Nickel, lead, and semivolatile organic compounds other than PCP were consistently undetected in both raw and treated waste analyses, and therefore are not included in the results of this report. For each analyte the results are reported as average values for six or more samples of raw and treated waste and include standard deviation values. In addition, the results include calculated percent reductions accounting for dilution effects of added reagents by incorporating the additives ratio for each batch tested. This ratio is the weight of additives, including water of hydration, divided by the weight of raw wastes.

Table B-1. Analytical and Measurement Methods

Title	Method	Raw Waste	Treated Waste	Reagent Mixture	Clean Sand	Process Water	Leachate	Digestates	6-Month Long-Term	6-Month Long-Term Leachate	18-Month Long- Term	18-Month Long-Term Leachate
TCLP	TCLP	•	•	•	•				•		•	
TCLP-Distilled Water	TCLP	•	•	•								
TCLP-Cage	TCLP-Cage		•	•								
CALWET	CALWET	•	•	•								
Modified ANS 16.1	Modified ANS 16.1		•	•								
Metals: Sb,Be,Cd,Cr, Cu,Ni,Ag,Zn, Pb,Na,Al,Ba, Ca,Co,Fe,Mg, Mn,Mo,K,V	3050	•	•	•	•							
	3010						•			•		•
	6010							•				
Pb,Tl,As,Se	3050	•	•	•	•							
	3020						•			•		•
Pb	7421							•				
Tl	7841							•				
As	7060						•	•		•		•
Se	7740						•	•		•		•
Hg	7471	•	•	•	•							
	7470						•			•		•
Volatile Organic Compounds	8240	•	•	•			•			•		•
Semivolatile Organic Compounds	8270	•	•	•			•	•		•		•
PCDDs and PCDFs	8280	•	•									

Table B-1. Analytical and Measurement Methods (continued)

Title	Method	Raw Waste	Treated Waste	Reagent Mixture	Clean Sand	Process Water	Leachate	Digestates	6-Month Long-Term	6-Month Long-Term Leachate	18-Month Long- Term	18-Month Long-Term Leachate
pH	EPA 9045	•	•	•	•							
	EPA 9040					•	•					
Eh	Modified EPA 9045	•	•	•	•							
	ASTM D-1498					•	•					
Neutralization Potential	Sobeck, 1978	•	•	•								
Loss On Ignition	ASTM C-114	•	•	•	•							
Oil and Grease	Modified EPA 413.2	•	•	•								
Particle Size	ASTM D-422	•			•							
Moisture Content	ASTM D-2216	•			•							
	TMSWC-4		•	•								
Bulk Density	ASA-13.2	•										
	TMSWC-2		•	•								
Permeability	TMSWC-13		•	•								
Unconfined Compressive Strength	ASTM D-1633		•	•							•	
Wet/Dry Weathering	TMSWC-12		•	•								
Freeze/Thaw Weathering	TMSWC-11		•	•								
Petrographic	Modified ASTM C457/C856	•	•	•								

Table B-2. Analytical Results for STC-Treated Wastes

Constituent	Batch	Concentrations (ppm)		Percent Reduction[b,c]
		Raw Waste[a]	Treated Waste[a]	
Arsenic - TCLP	1	1.82 ± 0.47	0.086 ± 0.055	92 (81.5 - 97.6)
	3	1.06 ± 0.23	0.101 ± 0.030	83 (72.2 - 90.3)
	4	2.40 ± 0.60	0.875 ± 0.153	35 (-1.43 - 57.3)
	5	3.33 ± 0.33	0.548 ± 0.095	71 (62.6 - 78.4)
	Sand	<0.01	---	---
	RM	---	<0.01	---
Arsenic - TCLP Distilled Water	1	0.80 ± 0.21	<0.01	>98 (97.0 - 98.3)
	3	0.73 ± 0.06	<0.01	>98 (97.3 - 97.8)
	4	1.25 ± 0.12	0.011 ± 0.001	98 (98.1 - 98.7)
	5	1.07 ± 0.09	0.012 ± 0.001	98 (97.7 - 98.3)
	RM	---	<0.01	---
Arsenic - TWA	1	470 ± 220	310 ± 40	---
	3	270 ± 60	198 ± 70	---
	4	1,700 ± 200	1,000 ± 120	---
	5	2,180 ± 320	1,550 ± 570	---
	Sand	<2	---	---
	RM	---	2.5	---
Arsenate (V)[d]	3	60.5	<2.0	---
	4	19.5	21	---
	5	260	<2.0	---
Arsenite (III)[d]	3	<2.0	<2.0	---
	4	205	7.5	---
	5	<2.0	<2.0	---

Table B-2. Analytical Results for STC-Treated Wastes (Continued)

Constituent	Batch	Concentrations (ppm)		Percent Reduction[b,c]	
		Raw Waste[a]	Treated Waste[a]		
Chromium - TCLP	1	0.13 ± 0.09	0.245 ± 0.005	-230	(-1,000 - (-92))
	3	<0.05	0.187 ± 0.012	NC	
	4	0.10 ± 0.06	0.278 ± 0.010	-390	(-1,179 - (-197))
	5	0.27 ± 0.05	0.320 ± 0.033	-110	(-181 - (-56))
	Sand	<0.05	---	---	
	RM	---	<0.07	---	
Chromium - TCLP Distilled Water	1	0.19 ± 0.07	<0.05	>54	(27 - 66)
	3	0.17 ± 0.05	<0.05	>48	(27 - 66)
	4	0.07 ± 0.01	0.056 ± 0.006	-42	(-84 - (-11))
	5	0.11 ± 0.04	0.079 ± 0.003	-25	(-105 - 12)
	RM	---	<0.05	---	
Chromium - TWA	1	410 ± 80	340 ± 10	---	
	3	340 ± 90	270 ± 50	---	
	4	1,750 ± 80	950 ± 60	---	
	5	2,120 ±210	1,270 ±160	---	
	Sand	<10	---	---	
	RM	---	12	---	

Table B-2. Analytical Results for STC-Treated Wastes (Continued)

Constituent	Batch	Concentrations (ppm)		Percent Reduction[b,c]	
		Raw Waste[a]	Treated Waste[a]		
Copper - TCLP	1	3.42 ± 1.16	0.090 ± 0.005	95	(92.6 - 96.7)
	3	1.38 ± 0.15	0.075 ± 0.007	90	(88.1 - 92.3)
	4	6.53 ± 1.11	0.103 ± 0.005	97	(96.5 - 97.7)
	5	9.43 ± 1.40	0.062 ± 0.012	99	(98.4 - 99.2)
	Sand	<0.03	---	---	
	RM	---	<0.03	---	
Copper - TCLP Distilled Water	1	0.45 ± 0.16	0.031 ± 0.001	88	(81.1 - 91.5)
	3	0.37 ± 0.08	<0.030	86	(81.4 - 88.3)
	4	0.99 ± 0.06	0.054 ± 0.002	90	(89.3 - 91.1)
	5	0.56 ± 0.10	0.032 ± 0.001	90	(87.4 - 92.0)
	RM	---	<0.03	---	
Copper - TWA	1	370 ± 47	280 ± 10	---	
	3	330 ± 48	210 ± 16	---	
	4	1,170 ± 52	630 ± 34	---	
	5	1,270 ± 52	780 ± 97	---	
	Sand	<6	---	---	
	RM	---	<6	---	

Table B-2. Analytical Results for STC-Treated Wastes (Continued)

Constituent	Batch	Concentrations (ppm)		Percent Reduction[b,c]	
		Raw Waste[a]	Treated Waste[a]		
PCP - TCLP	1	1.50 ± 0.13	3.42 ± 1.50	-302	(-532 - (-107))
	3	2.27 ± 0.33	<0.250	>81	(77 - 99)
	4	1.75 ± 0.57	5.52 ± 0.32	-460	(-779 - (-298))
	5	2.28 ± 1.40	0.90 ± 1.25	31	(-326 - 117)
PCP - TCLP Distilled Water	1	34.7 ± 16.4	3.98 ± 1.78	80	(44.7 - 92.4)
	3	40.0 ± 18.4	0.58 ± 0.08	97	(94.6 - 98.5)
	4	40.5 ± 10.5	3.87 ± 0.46	83	(74.4 - 88.1)
	5	79.7 ± 17.9	3.05 ± 0.85	93	(89.0 - 96.1)
PCP - TWA[e]	1	2,350 ± 660	120 ± 40	91	(83.3 - 95.3)
	3	1,980 ± 270	90 ± 30	92	(87.6 - 95.3)
	4	7,700 ± 1,080	120 ± 40	97	(95.7 - 98.4)
	5	8,320 ± 1,440	220 ± 150	95	(90.6 - 98.7)
PCP - TCLP pH 12[d,f]	1	110	6.2	90	
	3	88	1.9	96	
	4	320	13	93	
	5	320	17	91	

Arsenic and PCP were target analytes for treatment for the technology demonstration; chromium and copper were not.

RM = *Reagent mixture*

NC = *Not calculable*

a = *Results for individual batches reported as the mean and standard deviation of six or more samples.*

b = *Percent Reduction* = $\left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$

The low end of the percent reduction range was calculated by subtracting the standard deviation from the raw waste mean and adding the standard deviation to the treated waste mean to produce a worst-case value. The high end of the percent reduction range was calculated by adding the standard deviation to the raw waste mean and subtracting the standard deviation from the treated waste mean to produce a best-case value.

c = *The additives ratio is the weight of additives including water of hydration, divided by the weight of raw wastes. Values are 0.761, 0.764, 0.776, and 0.746 for Batches 1, 3, 4, and 5, respectively.*

d = *Results reported as mean of duplicate analyses.*

e = *Estimated average concentrations using twice the method detection limit for non-detected analyses.*

f = *0.1 M borate buffer solution used in leaching.*

Thus, percent reduction was calculated using the following formula:

$$\textit{Percent Reduction} = \left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$$

When a constituent was not detected in the treated waste, the reporting limit for the treated waste constituent was used to calculate a minimum value for the percent reduction (indicated by ">").

Reporting limits were determined by multiplying the method detection limit by the dilution factor for each specific analysis. The reporting limits were not considered useful for TWA of post-treatment PCP due to very large dilution factors required to reach the quantitation range for PCP analysis, thus forcing the reporting limits for PCP to unreasonably high levels. The STC TER reports the results of additional analyses of raw and treated waste samples that were analyzed for PCP by TWA using non-standard dilution steps to obtain lower reporting limits. These results justify the use of estimated concentrations in calculating percent reductions and generally show even greater percent reductions than using the estimated values. Treated waste concentrations for total waste analysis of PCP, therefore, consist of estimates using twice the method detection limit for non-detected analyses. Such an estimate is more reasonable, yet still conservative. If a constituent was not detected in the raw waste, the percent reduction was not calculable. As a result of the dilution associated with treatment, negative percent reduction values may be expected even if the concentrations show a decrease in concentration from the raw to the treated waste.

In general, the percent recovery for semivolatile surrogates, and acid surrogates in particular, were consistently extremely low. In many of the samples containing the reagent mix, no acid surrogates were recovered. These results suggest that a significant portion of the spiked compounds remained adsorbed to the reagent mixture during the analysis. These results also indicate that the reagent mixture would have the same effect on target compounds similar to the surrogates. This trend supports the effectiveness of the reagent mixture on phenolic compounds since all three acid surrogate compounds were phenols.

Inorganics

Although arsenic was the main metal contaminant of regulatory concern at the SPT site, chromium, copper, nickel, and lead were also analyzed in replicate samples using the various leach tests and TWA analysis. Nickel and lead were consistently undetected in both raw and treated waste analyses and therefore are not included in the results of this report. In addition, routine analyses were performed for the 23 standard Hazardous Substance List (HSL) metals, plus molybdenum (which is included in the CALWET testing). These analyses typically did not identify additional anomalously high concentrations of metals other than elements commonly found in soils, such as iron and aluminum. Thus, the metals selected for this report are limited to arsenic, chromium, and copper. TWA results for the selected metals are included in this report despite the fact that concentrations of *total* metals are not expected to be reduced by the STC process; therefore, percent reductions have not been included. Metal analyses of the water and silica sand additives for TWA and TCLP are presented in Table B-3. In addition, Table B-4 presents metal analyses of STC's reagent mixture with clean sand for the various leach tests and TWA.

Arsenic

In general, leach results indicated that arsenic was well stabilized by the STC treatment under neutral conditions. Acidic leaching, as under TCLP conditions, resulted in greater arsenic mobility for both the raw and treated waste. This observed increased arsenic mobility is, at least in part, due to the amphoteric nature of arsenic, whereby its solubility increases as the pH of the leachate either decreases or increases away from neutral conditions.

Using the TCLP, results for arsenic varied among the four batches evaluated, with percent reductions ranging from 35 to 92 percent. Batch 4 depicts an anomalously low percent reduction of only 35 percent. This poorer-than-expected performance may be attributed to the inordinately long raw-waste-mixing time for this batch (4.5 hours). Supplemental ion

Table B-3. Metal Analyses of Water and Sand Additives

Constituent	Water - TWA[a] (ppm)	Sand - TWA (ppm)	Sand - TCLP (ppm)
Aluminum	<0.2	780	0.30
Arsenic	<0.01	<2	<0.01
Calcium	20	310	11
Chromium	<0.05	<10	<0.05
Copper	<0.03	<6	<0.03
Iron	0.05	1,200	<0.1
Magnesium	4.1	<200	<1
Manganese	<0.02	9.3	0.072
Potassium	2.15	<200	1.1
Sodium	17	<200	1,300
Zinc	0.037	<4	0.053

a = Results reported as mean of duplicate samples.

Table B-4. Metal Analyses of Reagent Mixture (Sand Plus Reagents)

Constituent	TWA (ppm)	TCLP (ppm)	TCLP Distilled Water (ppm)	TCLP-Cage (ppm)	CALWET (ppm)
Aluminum	4,300	<0.2	0.56	<0.2	15
Arsenic	2.5	<0.01	<0.01	<0.07	<0.1
Barium	27	0.21	0.40	0.21	<1
Calcium	61,000	1,900	660	2,000	1,200
Chromium	12	0.07	<0.05	0.053	<0.5
Copper	<6	<0.03	<0.03	<0.03	<0.3
Iron	3,100	<0.05	<0.05	<0.05	24
Magnesium	930	5.5	<1	11	<10
Manganese	27	<0.02	<0.02	<0.02	0.32
Potassium	1,400	19	19	15	51
Selenium	<1	---	<0.005	0.006	<0.05
Sodium	1,100	16	14	23	8,600
Zinc	8.1	<0.02	<0.02	<0.02	0.39

chromatography analyses of arsenic for selected TWA extracts from Batches 3, 4, and 5 indicate that the raw waste from Batch 4 contained higher quantities of the arsenic ion-species arsenite (205 ppm) and lower values of arsenate (20 ppm) relative to Batches 3 and 5 that had high arsenate (61 and 260 ppm, respectively) and low arsenite values (<2 ppm in both batches). It is likely that most of the Batch 4 arsenic was reduced from arsenate (V) to arsenite (III) during the long raw-waste-mixing process, thereby rendering the treated contaminants more mobile and easily leached under acidic TCLP conditions. Alternatively, the STC process was not effective in converting the arsenite to arsenate or a species which could be chemically immobilized; minor amounts of both arsenite and arsenate were detected in the Batch 4 treated waste.

Excluding results from Batch 4, percent reductions for arsenic under TCLP conditions range from 71 to 92 percent. Values for arsenic as analyzed by the TCLP-Distilled Water method show the highest percent reductions of 98 percent for all four batches. This leach method was not affected by the arsenic speciation differences observed in Batch 4. Concentrations of arsenic were, however, lower than TCLP regulatory levels in each of the four batches for both the raw and treated wastes.

Chromium

Due to low leachable concentrations in the raw waste, chromium was not a contaminant targeted for treatment during the demonstration. That is, no special measures were taken to treat chromium. Therefore, the STC treatment process was not as consistently effective in immobilizing chromium as it was for arsenic. Chromium was generally rendered immobile by STC's treatment process under neutral leaching conditions. However, under acidic leaching conditions, chromium was more mobile and leachable in the treated waste; chromium concentrations for the treated wastes were significantly higher than for the raw wastes in all but one treatment batch. The results indicate that if chromium is targeted for treatment, the combination of treatment additives should be adjusted to make the treatment more effective.

TCLP tests for chromium showed large negative values for percent reduction ranging from -107 to -394 percent. Leachate concentrations of chromium from the raw waste of Batch 3 were below detection limits and therefore percent reductions were not calculable. Values from analysis using the TCLP-Distilled Water method showed more variability with percent reductions ranging from -42 percent to greater than 54 percent. It should be noted, though, that all of the TCLP-Distilled Water values for the treated waste were at or near the detection limit as were the concentrations of chromium in the raw waste for the batches resulting in negative percent reduction values.

TWA analyses of the STC reagent mixture indicated an addition of small amounts of chromium (12 ppm) as a result of the STC treatment process. In addition, TCLP leachate from the reagent mixture indicated that 22 to 37 percent of the concentration of leachable chromium in the treated waste was a result of the treatment process.

The raw waste showed no differences in leachability between acidic and neutral TCLP conditions. Furthermore, despite the large batch-to-batch range of total chromium concentrations in the raw waste, the leachate concentrations of the raw waste under both acidic and neutral TCLP conditions are essentially the same. (That is, the distribution of leachate concentrations overlap.) However, leachable chromium concentrations in the raw waste are very low -- well below regulatory levels for the TCLP. Treated waste concentrations of chromium were also below these regulatory levels.

Copper

Copper was not a targeted contaminant for treatment during this demonstration. However, treated waste leachate concentrations indicated that copper was effectively stabilized under both acidic and neutral TCLP conditions. Copper in the raw waste was considerably less mobile under neutral conditions than under acidic leaching conditions.

Both the TCLP and the TCLP-Distilled Water methods of analysis showed consistently high percent reductions of copper. The TCLP percent reduction values ranged from 90 to 99 percent while the TCLP-Distilled Water method indicated only slightly less effective treatment with percent reduction values ranging from 86 to

90 percent (although the pretreatment concentrations of copper were much lower under neutral conditions). Initial copper concentrations in the raw wastes for both the TCLP and TCLP-Distilled Water tests were low (<10 ppm and <1 ppm, respectively); however, no TCLP regulatory threshold concentration has been established for copper.

Organics

Pentachlorophenol (PCP) was the main organic contaminant of concern at the SPT site. Based on the information from the treatability study at the site, however, replicate samples were also analyzed for other constituents including semivolatile organics such as tetrachlorophenol (TCP), phenanthrene, naphthalene, and phenol. These constituents were ultimately detected in negligible concentrations, and therefore were not included in this report.

Pentachlorophenol (PCP)

PCP concentrations for the TWA extracts show percent reductions as a result of the STC stabilization process ranging from 91 to 97 percent. Results of the TCLP at varying pH levels (waste sample size, leachate volume and leaching time the same as for the standard TCLP) indicated that the leachability of PCP in the raw waste was a function of pH. Raw waste leachates showed greater PCP mobility under neutral TCLP-Distilled Water leaching conditions than under the standard acidic TCLP conditions. Although TCLP analysis at pH 12 is not a standardized leach test, this method (using a 0.1 M borate buffer solution) indicated better results for PCP than either the standard TCLP or neutral TCLP-Distilled Water leach tests. Percent reductions for PCP by TCLP analysis conducted at pH 12 ranged from 90 to 96 percent.

The treated waste showed similar leaching characteristics for both acidic and neutral conditions. Even the TCLP at pH 12 leachate concentrations of PCP for Batch 1 and 3 were comparable to neutral and acidic leach conditions. As a result of the lower leachate concentrations from the raw wastes, the percent reductions for PCP range from -460 to 81 percent for the TCLP (two of the four batches showed increases in PCP concentrations of the treated wastes), and 80 to 97 percent based on the neutral TCLP-Distilled Water test method. All raw and treated waste concentrations were, however, below TCLP federal regulatory threshold levels of 100 ppm for PCP.

Summary of Other Measurements

Noncritical testing parameters, as outlined in the STC Demonstration Plan and the QAPjP, include CALWET, TCLP-Cage, and modified ANS 16.1 leach tests on stabilized waste samples. In addition, results for chemical analysis for oil and grease are included in this section. Each of these analyses was performed on both raw and treated wastes. Soil chemical characterization parameters including pH, Eh, loss on ignition, and neutralization potential for both raw and treated wastes, and the solidified reagent mixture are also briefly discussed. Soil physical parameters and geotechnical analyses include mean particle size, moisture content, bulk density, unconfined compressive strength, permeability, wet/dry and freeze/thaw weathering. Finally, petrographic examination and X-ray analyses are provided for generalized qualitative descriptions of raw and treated waste material. More detailed information is contained in the STC TER.

CALWET

The CALWET consists of an extraction similar to that of the TCLP extraction, except that the CALWET uses a citric acid solution for leaching solid material over a 48-hour period, at a liquid-to-solid ratio of 10 to 1. Following the leaching period, separation of the extracts is achieved by filtration through a 0.45 μm membrane filter, centrifuging prior to filtration if necessary. As a result of the greater acid strength, longer leaching time, and greater buffering capacity, the CALWET is a more aggressive leach procedure than the TCLP. Analytical results for the CALWET are presented in Table B-5.

Raw waste leachate concentrations of PCP and arsenic were above the Solubility Threshold Limit Concentrations (STLC) for the CALWET, a criteria used by the state of California (see Table 3-6). Chromium concentrations were well below the total chromium STLC of 560 ppm, and hexavalent chromium was not specifically analyzed. Copper showed mixed results with the raw waste leachate from Batch 3 below the STLC of 25 ppm and Batches 1, 4, and

Table B-5. Analytical Results for CALWET

Constituent	Batch	Concentrations (ppm)		Percent Reduction [b,c]	
		Raw Waste[a]	Treated Waste[a]		
Arsenic	1	12.7 ± 1.53	4.57 ± 1.07	36.6	(11.1 - 56.7)
	3	8.8 ± 0.57	4.55 ± 1.39	8.5	(-27.8 - 40.3)
	4	28.7 ± 0.58	23.3 ± 1.63	-44.2	(-57.6 - (-31.4))
	5	28.0 ± 1.73	20.0 ± 3.41	-24.7	(-55.6 - 2.57)
Chromium	1	2.97 ± 0.12	5.15 ± 0.96	-205	(-277 - (-139))
	3	2.07 ± 0.15	3.80 ± 0.36	-224	(-282 - (-173))
	4	7.10 ± 0.56	19.0 ± 1.10	-375	(-446 - (-315))
	5	6.90 ± 0.30	18.0 ± 1.10	-355	(-405 - (-310))
Copper	1	27.7 ± 0.58	12.3 ± 1.63	21.8	(9.55 - 33.6)
	3	17.7 ± 0.58	8.8 ± 0.45	12.0	(4.38 - 19.1)
	4	57.7 ± 3.51	31.8 ± 1.1	2.12	(-7.43 - 10.6)
	5	61.3 ± 4.73	33.0 ± 1.10	6.01	(-5.25 - 15.7)
PCP	1	2.30 ± 0.56	12.3 ± 2.08	-842	(-1,356 - (-530))
	3	2.60 ± 0.44	3.5 ± 1.16	-135	(-277 - (-35))
	4	3.20 ± 0.10	28.7 ± 4.62	-1,493	(-1,809 - (-1,196))
	5	2.87 ± 0.15	31.7 ± 2.89	-1,829	(-2,123 - (-1,564))

Arsenic and PCP were target analytes for treatment for the technology demonstration; chromium and copper were not.

a = *Results reported as the mean and standard deviation of three or more samples.*

b = *Percent Reduction* = $\left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$

The low end of the percent reduction range was calculated by subtracting the standard deviation from the raw waste mean and adding the standard deviation to the treated waste mean to produce a worst-case value. The high end of the percent reduction range was calculated by adding the standard deviation to the raw waste mean and subtracting the standard deviation from the treated waste mean to produce a best-case value.

c = *The additives ratio is the weight of additives, including water of hydration, divided by the weight of raw wastes. Values are 0.761, 0.764, 0.776, and 0.746 for Batches 1, 3, 4, and 5, respectively.*

5 above this limit.

STC-treated wastes were not effectively stabilized based on results from the CALWET procedure. PCP concentrations in the treated waste leachates were greater than those for the raw waste leachates, thus resulting in very large negative percent reductions ranging from -135 to -1,829 percent. Arsenic values showed mixed results, with percent reductions ranging from -44 to 37 percent. Although all batches showed reductions in arsenic leachate concentrations, only Batches 1 and 3 resulted in leachate concentrations below the STLC of 5 ppm. Leachate concentrations of chromium, like PCP, increased following the STC treatment based on the CALWET, resulting in negative percent reductions ranging from -205 to -375 percent. Chromium leachate concentrations, however, remained below the STLC limit of 560 ppm. Copper concentrations were slightly reduced upon treatment; however, only Batch 1 was brought below the STLC of 25 ppm for the treated CALWET leachates. Batch 3 was below this threshold prior to treatment. Overall, percent reductions for copper ranged from 2 to 22 percent.

TCLP-Cage Test (Modified TCLP)

Table B-6 depicts TCLP-Cage analyses and compares the results with post-treatment TCLP and TCLP-Distilled Water tests for arsenic, chromium, copper, and PCP. The TCLP-Cage test determines the amount of constituents leachable from a monolith of solidified/stabilized waste. This leach test is a modified form of the TCLP test in that the sample is subjected to an acidic leaching medium but is not crushed or ground prior to leaching. Otherwise, the waste is leached in an identical manner as in the standard TCLP.

One would expect greater leaching under standard TCLP test conditions due to the increased exposed surface area resulting from crushing the solidified waste; however, this was not typically the case for metals. For the metals, all but three cases showed higher concentrations in the TCLP-Cage leachate when compared to the TCLP; however, the results were highly variable especially for chromium and copper where standard deviation values exceeded mean values. For PCP, on the other hand, the lowest leachate concentrations were obtained for the TCLP-Cage test in all batches, except Batch 3 for which PCP was not detected in both the TCLP and TCLP-Cage tests. All TCLP, TCLP-Cage, and TCLP-Distilled Water values for the treated waste samples were well below the regulatory levels for the TCLP except for copper for which regulatory levels have not yet been established). However, raw waste samples were also well below these levels.

ANS 16.1 Test

The ANS 16.1 leach test simulates leaching of a stabilized waste with rapidly flowing ground water by using a static sequential leaching method. A 10-week modification of the ANS 16.1 leach test was used to approximate leaching from intact solidified waste samples using demineralized water flowing around the waste samples (the initial leach periods were lengthened because previous experience indicated that solidified matrices were barely wetted during the standard ANS 16.1 leach periods).

Results of the leachate analyses are presented in Table B-7. Only negligible amounts of each of the three selected metals -- arsenic, chromium, and copper -- were detected in the leachates after each test period. Except for chromium after the second test period, all metal values were at or near the minimum reporting limits. PCP results were slightly higher than minimum reporting limits, although they were still very low. As part of the ANS 16.1 leachability test, the leachability index (LI) is recommended as a standard method for evaluating solidified waste forms. The leachability index is defined as:

$$LI = \log\left(\frac{1}{D_e}\right)$$

where D_e is the effective diffusion coefficient; calculation of D_e is further discussed in the STC TER. This index is used to compare the relative mobility of contaminants on a uniform scale. This scale varies from very mobile for a value of 5 to immobile for values of 15 or greater. The ANS 16.1 leachability index was calculated from the leach results for arsenic, chromium, copper, and PCP. The values of the leachability indices are as follows:

Table B-6. Results of TCLP, TCLP-Cage, and TCLP-Distilled Water for Treated Wastes

Constituent	Batch	Concentrations (ppm)[a]		
		TCLP	TCLP - Cage	TCLP Distilled Water
Arsenic	1	0.086 ± 0.055	0.327 ± 0.025	<0.01
	3	0.101 ± 0.030	0.117 ± 0.011	<0.01
	4	0.875 ± 0.153	0.740 ± 0.201	0.011 ± 0.001
	5	0.548 ± 0.095	0.253 ± 0.040	0.012 ± 0.001
Chromium	1	0.245 ± 0.005	0.607 ± 0.240	<0.05
	3	0.187 ± 0.012	0.140 ± 0.010	<0.05
	4	0.276 ± 0.010	0.660 ± 0.819	0.056 ± 0.006
	5	0.320 ± 0.034	0.573 ± 0.637	0.079 ± 0.003
Copper	1	0.090 ± 0.005	1.61 ± 0.689	0.0303 ± 0.0008
	3	0.075 ± 0.008	0.096 ± 0.004	0.0302 ± 0.0004
	4	0.103 ± 0.005	1.43 ± 2.23	0.0542 ± 0.0018
	5	0.062 ± 0.012	1.80 ± 2.29	0.0317 ± 0.0014
PCP	1	3.42 ± 1.50	1.190 ± 1.70	3.98 ± 1.770
	3	<0.250	<0.250	0.58 ± 0.083
	4	5.52 ± 0.32	0.167 ± 0.072	3.87 ± 0.459
	5	0.804 ± 1.17	0.074 ± 0.001	3.05 ± 0.846

a = Results reported as the mean and standard deviation of six samples.

Table B-7. ANS 16.1 Leachate Analyses for STC-Treated Waste (Batch 3)

Constituent	Concentrations (ppm)[a]				
	Day 14	Day 28	Day 42	Day 56	Day 70
Arsenic	<0.004	0.004 ± 0.001	<0.004	<0.004	<0.004
Chromium	<0.01	0.046 ± 0.070	0.019 ± 0.012	0.0100 ± 0.0004	<0.01
Copper	0.022 ± 0.003	<0.02	0.027 ± 0.010	<0.02	<0.02
PCP	0.235 ± 0.094	0.125 ± 0.038	0.125 ± 0.034	0.127 ± 0.030	0.104 ± 0.020
pH	11.6	11.6	11.0	11.2	11.0

a = Results reported as mean and standard deviation of three samples plus a duplicate.

Arsenic	-	LI = 12.2
Chromium	-	LI = 11.0
Copper	-	LI = 10.9
PCP	-	LI = 10.8

These values are well above the Nuclear Regulatory Commission's minimum leachability index standard of 6. However, the standard for this index has no specific basis in terms of human or environmental risk or toxicity and therefore is not sufficient to guarantee that the products of the process are protective of human health and the environment if they are placed in a landfill.

Oil and Grease Analysis

Oil and grease extracts were analyzed for both raw and treated wastes, and the results are reported in Table B-8. Calculated percent reductions ranged from 32 to 52 percent. Although the STC treatment process was not especially effective in reducing the amount of extractable oil and grease in the SPT waste, the presence of small quantities (< 2 percent) of oil and grease did not appear to adversely affect the solidification of the waste as determined by the petrographic observations (discussed below).

pH, Eh, Loss on Ignition, and Neutralization Potential

Additional chemical waste characterization consisted of determining the pH, Eh, loss on ignition, and neutralization potential for both raw and treated wastes. These results are summarized in Table B-9. Results for pH, Eh, and loss on ignition are also presented for STC's solidified reagent mixture, sand, and water additives (Table B-10).

Raw waste samples were slightly acidic to neutral with pH values ranging from 6.3 to 7.1. Treated wastes were very basic with pH values of 12.5 to 12.6. The sand and water additives had slightly basic characteristics with a pH of 8.6 and 8.0 respectively, and the STC reagent mixture was very basic with a pH of 12.5.

Oxidation-reduction potential, measured in terms of Eh (millivolts), ranged from 389 to 421 for the raw waste, with slightly lower values of 366 and 368 for sand and water additives respectively. The STC reagent mixture and treated wastes reveal much lower Eh values of 144 and 162.7 to 174.3, respectively. This decrease in the reduction/oxidation potential indicates a less ox-

Table B-8. Oil and Grease Analysis

Constituent	Batch	Concentrations (ppm)		Percent Reduction[b,c]	
		Raw Waste[a]	Treated Waste[a]		
Oil and Grease	1	10,667 ± 577	3,733 ± 252	38.4	(30.5 - 45.5)
	3	11,667 ± 557	3,200 ± 200	51.6	(45.9 - 56.8)
	4	19,000 ± 1,000	7,300 ± 608	31.8	(22.0 - 40.6)
	5	19,667 ± 577	7,400 ± 361	34.3	(29.0 - 39.3)

a = Results reported as the mean and standard deviation of three samples.

b = Percent Reduction = $\left[1 - (1 + \text{Additives Ratio}) \times \frac{\text{Concentration of Treated Waste}}{\text{Concentration of Raw Waste}}\right] \times 100.$

The low end of the percent reduction range was calculated by subtracting the standard deviation from the raw waste mean and adding the standard deviation to the treated waste mean to produce a worst-case value. The high end of the percent reduction range was calculated by adding the standard deviation to the raw waste mean and subtracting the standard deviation from the treated waste mean to produce a best-case value.

c = The additives ratio is the weight of additives, including water of hydration, divided by the weight of wastes. Values are 0.761, 0.764, 0.776, and 0.746 for Batches 1, 3, 4, and 5, respectively.

Table B-9. Analytical Results for pH, Eh, Loss on Ignition, and Neutralization Potential for Raw and Treated Waste

Analysis	Batch	Raw Waste[a]	Treated Waste[a]
pH (pH units)	1	7.1	12.5
	3	6.9	12.6
	4	6.3	12.5
	5	6.9	12.5
Eh (mV)	1	388.7	162.7
	3	393.3	164.7
	4	421.0	165.7
	5	399.3	174.3
Loss on Ignition (%)	1	6.87	24.7
	3	6.27	24.3
	4	7.70	26.1
	5	8.33	26.2
Neutralization Potential (meq/gram)	1	0.14	3.7
	3	0.13	3.7
	4	0.12	3.6
	5	0.15	3.7

a = Values are averages of duplicate analyses.

Table B-10. pH, Eh, Loss on Ignition and Neutralization Potential for Sand, Water, and STC Reagent Mixture

Analysis	Sand	Water[a]	Reagent Mixture
pH (pH units)	8.6	8.0	12.5
Eh (mV)	366	368	144
Loss on Ignition (%)	12.2	---	17.6
Neutralization Potential (meq/gram)	---	---	3.7

a = Values are averages of duplicate analyses.

idizing environment as a result of treatment.

Loss on ignition determines the weight loss of a sample that has been ignited in a muffle furnace at 950°C. The result represents total moisture (including water of hydration) and carbon content of a cementitious sample. Percent loss on ignition values range from 6.27 to 8.33 percent for the raw waste with the sand value at 12.2 percent loss. The STC reagent mixture lost 17.6 percent upon ignition, while the treated wastes had values of 24.3 to 26.2 percent loss.

The neutralization potential of cementitious reagents and treated wastes, reported in terms of milliequivalents (meq) per gram, measures the amount of neutralizers present in the material. This measurement is found by treating a sample with known amount of standardized hydrochloric acid, heating to assure complete reaction, and titrating with a standardized base. The result is expressed in calcium carbonate equivalents and represents tons of calcium carbonate available to neutralize 1,000 tons of material, based on the assumption that an acre plow-layer contains 2 million pounds of soil. Neutralization potential values for the raw waste ranged from 0.12 to 0.15 meq/gram. The reagent mixture and treated waste both had higher average values of 3.7 meq/gram.

Soil Physical Characteristics

Raw waste physical characterization consisted of mean particle size, moisture content, and bulk density measurements. These results are presented in Table B-11. Post-treatment physical characteristics are presented in Tables B-12 through B-14 and include moisture content, bulk density, permeability, unconfined compressive strength, and wet/dry and freeze/thaw weathering.

The mean particle size of the raw waste ranged from approximately 0.06 to 0.07 mm indicating a very-fine sand texture. The added coarse sand had a mean particle size of 0.65 mm. Moisture content of the raw waste was low ranging from 3.9 to 5.8 percent with the sand at 6.1 percent. Moisture content of the treated wastes, although also low, varied more -- from 1.9 to 9.7 percent with up to 7.7 percent standard deviation. The treated reagent mixture had a moisture content of 4.1 percent.

Average bulk densities ranged from 1.42 to 1.54 g/cm^3 for the raw waste. Treated waste samples show slightly higher average bulk densities ranging from 1.55 to 1.62 g/cm^3. The treated reagent mixture had an average bulk density of 1.92 g/cm^3. Calculated volume changes based on these data show volume increases ranging from approximately 59 to 75 percent.

Falling-head permeability rates were determined using a triaxial cell by measuring changes of water volume over time under controlled temperature and pressure conditions. Average permeability values for the treated waste ranged from 0.8 x 10^{-7} to 1.7 x 10^{-7} cm/sec. The solidified reagent mixture had an average permeability of 1.5 x 10^{-7} cm/sec. These values are of the same order of magnitude as the permeability requirements for hazardous waste landfill soil barrier liners of 10^{-7} (40 CFR part 264, subpart N).

Unconfined compressive strength (UCS) is the load per unit area, measured in pounds per square inch (psi), at which an unconfined solid cylindrical sample fails a compression test. Average UCS values for the treated wastes ranged from 259 to 347 psi. These values are significantly below the American Society for Testing and Materials (ASTM)/American Concrete Institute (ACI) minimum required unconfined compressive strength of 3,000 psi for the construction of sidewalks (ASTM, 1991). However, the measured UCS values are well above the EPA minimum guideline of at least 50 psi for hazardous waste solidification (U.S. EPA, 1986).

Wet/dry and freeze/thaw weathering tests assess the structural integrity of treated wastes when exposed to adverse weather conditions. Tables B-13 and B-14 present the cumulative corrected relative weight loss percentages over a period of 12 days for the treated waste as well as the solidified reagent mixture. These data show less than 1 percent relative weight loss, indicating good structural stability of the solidified waste for the time frame studied. Visual inspection of the samples also verified that samples remained intact throughout the 12-day test cycle. However, long-term extrapolation of such limited weathering data may yield erroneous conclusions about the stability of the STC solidified waste.

Table B-11. Physical Characteristics of Raw Wastes and Sand

Batch	Mean Particle Size (mm)[a]	Moisture Content (%)[a,b]	Bulk Density[a] (g/cm^3)
1	0.063 ± 0.006	5.8 ± 1.6	1.42 ± 0.13
3	0.063 ± 0.003	5.7 ± 1.7	1.54 ± 0.17
4	0.074 ± 0.010	4.2 ± 2.3	1.54 ± 0.17
5	0.073 ± 0.003	3.9 ± 2.5	1.54 ± 0.17
Sand	0.65	6.1 ± 2.5	---

a = Results reported as the mean and standard deviation of three or more samples.

b = Calculated from weight loss at 105 °C; moisture content = $\frac{(\text{wet weight} - \text{dry weight})}{\text{dry weight}} \times 100.$

Table B-12. Physical Characteristics of STC-Treated Wastes and Reagent Mixture

Batch	Moisture Content (%)[a,b]	Bulk Density (g/cm^3)[a]	Permeability (cm/sec)[a]	UCS (psi)[a]
1	2.6 ± 0.38	1.57 ± 0.03	$1.7 \times 10^{-7} \pm 0.40 \times 10^{-7}$	301 ± 162
3	1.9 ± 0.25	1.55 ± 0.02	$1.5 \times 10^{-7} \pm 0.98 \times 10^{-7}$	278 ± 20
4	9.7 ± 7.65	1.58 ± 0.01	$0.9 \times 10^{-7} \pm 0.41 \times 10^{-7}$	259 ± 65
5	8.8 ± 3.81	1.62 ± 0.04	$0.8 \times 10^{-7} \pm 0.47 \times 10^{-7}$	347 ± 65
RM	4.1 ± 2.82	1.92 ± 0.02	$1.5 \times 10^{-7} \pm 0.27 \times 10^{-7}$	682 ± 144

RM = Solidified reagent mixture

a = Results reported as the mean and standard deviation of three or more samples.

b = Calculated from weight loss at 60 °C; moisture content = $\frac{(\text{wet weight} - \text{dry weight})}{\text{dry weight}} \times 100.$

Table B-13. Wet/Dry Weathering of STC-Treated Wastes

Batch	Cumulative Corrected Relative Weight Loss (%)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.03	0.04	0.02	0.01	0.01	0.00	-0.01	-0.02	-0.01	-0.03	-0.04	-0.04
3	0.00	-0.01	-0.04	-0.05	-0.06	-0.08	-0.08	-0.10	-0.14	-0.16	-0.18	-0.21
4	0.02	0.01	-0.01	-0.01	-0.05	-0.06	-0.09	-0.13	-0.14	-0.17	-0.19	-0.20
5	0.03	0.02	0.02	0.01	-0.02	-0.03	-0.07	-0.08	-0.11	-0.13	-0.16	-0.17
RM	0.02	0.02	0.04	0.04	0.02	0.02	0.00	0.001	-0.01	-0.01	-0.02	-0.02

RM = Solidified reagent mixture

Table B-14. Freeze/Thaw Weathering of STC-Treated Wastes

Batch	Cumulative Corrected Relative Weight Loss (%)											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	0.01	0.01	0.03	0.02	0.04	0.05	0.04	0.04	0.04	0.06	0.09
3	-0.02	-0.05	-0.04	-0.05	-0.05	-0.04	-0.04	-0.01	-0.03	-0.02	-0.01	0.02
4	-0.02	-0.03	-0.04	-0.03	-0.04	-0.05	-0.07	-0.10	-0.09	-0.05	-0.04	-0.01
5	0.00	-0.02	-0.03	-0.03	-0.05	-0.05	-0.07	-0.08	-0.08	-0.07	-0.08	-0.09
RM	-0.03	-0.05	-0.04	-0.04	-0.01	0.03	0.04	0.07	0.09	0.15	0.18	0.22

RM = Solidified reagent mixture

Petrographic Analyses

Contaminated soils and solidified samples from each of the individual test batches including the STC reagent mixture were examined using optical microscopy, scanning electron microscopy (SEM), X-ray diffraction (XRD), and Fourier transform infrared spectroscopy (FTIR) techniques.

Petrographic observations of the materials provided information on the homogeneity of mixing, distribution of the matrix, and characteristics of the microstructure. Raw waste samples consisted mainly of very-fine grained (<0.2 mm) quartz, feldspars (potassium feldspars and plagioclase), hornblende, clay, mica, and granite pebbles up to 10 mm diameter. Wood fragments and other organic debris were observed in small amounts. Clumps of clay-sized material appeared to be held together by an oily substance, and larger particles typically had shiny coatings of oil.

The solidified wastes and reagent material were well consolidated, with air voids estimated at 3 to 7 percent. The black opaque binder material was moderately soft, evenly distributed with a moderately tight binder-aggregate bond. Carbonation of the binder around air voids indicated a reaction between calcium hydroxide (portlandite) and air. In addition, small amounts of greenish-brown glassy slag and traces of residue portland-cement clinker were observed. The soil-binder system appeared to be well mixed based on distribution and size of soil aggregates (2 to 4 mm diameter). Clumps with diameters up to 1 cm were typically surrounded by a tar-like rim. Faint layering was observed in several samples.

A summary of the petrographic observations is presented in Table B-15. Batch 1 included a quality control sample (1-QC). The binder distribution for both samples from Batch 1 was nonuniform. In addition, one sample from Batch 1 was underconsolidated compared to the other batch samples that were all well consolidated. Batch 1 was the only batch analyzed that was not sieved as part of the pretreatment process.

Results of XRD analyses are presented in Table B-16. Conclusions from the petrographic analyses concerning the binder and soil materials were confirmed by the XRD examination. These analyses also indicate that the STC process used predominantly silica and potassium-aluminum silicates in addition to calcium hydroxide and sulfates to form the binding agent.

SEM analyses indicated relatively good binder-to-aggregate bonding except in rare cases where oily particle coatings prevented adequate bonding. However, the quality of the surrounding binder sufficiently macroencapsulated such particles. The following elements were commonly detected using an energy dispersive X-ray (EDX) fluorescence probe in conjunction with the SEM: calcium, silicon, iron, aluminum, potassium, and chlorine, with minor amounts of sulfur, arsenic, chromium, titanium, and copper. Elemental maps of heavy metal contamination suggest good containment of the metals; mixing of binder and waste followed by consolidation did not appear to cause migration of metals from contaminated particles into the surrounding material.

FTIR analyses showed that organic materials were volatilized at 200°C and 300°C in the raw waste samples. There was no evidence for the presence of condensed organic compounds below 200°C or above 300°C. The total amount of organic materials volatilized from these samples was approximately 1 to 2 percent. Substantial amounts of adsorbed water were also released from the raw waste samples upon heating. Infrared analysis identified the organic materials volatilized from the raw wastes as a mixture of aliphatic and aliphatic-substituted aromatic hydrocarbon compounds. The spectra showed evidence for the presence of carboxylic acid groups, and nitrogen-hydrogen bonds, present as amine or amide groups. This composition is consistent with the residue from a heavy oil, such as diesel fuel. PCP was not specifically detected in the infrared spectra of the organic pyrolyzates in the raw waste; however, a minimum concentration of 10,000 ppm (1 percent) PCP is required for detection using FTIR analyses. Average TWA concentrations of PCP in the raw waste did not exceed this minimum concentration. In addition, PCP may be strongly adsorbed to the soil and therefore all of the PCP present in a sample may not be released upon heating. More aggressive chemical extraction procedures are required to release all of the PCP. Additional analyses to quantify the amount of PCP volatilization at varying temperatures are presented in the STC TER.

Pyrolysis of the treated wastes showed almost no evidence for the release of organic species, from either large chunks (3/8-inch diameter) or processed powder (<150 mesh). One exception yielded a small amount of primarily aliphatic hydrocarbon species, after pyrolysis of the sample in chunk form at 400°C.

Long-Term Tests

Long-term chemical monitoring of the STC-treated waste showed whether the potential leachability of TCLP extracts for metals and TWA for PCP of the treated waste were affected by aging. Results for analyses of 6- and 18-month cured samples are presented in Table B-17. Averages of six samples for the 6-month analyses and four samples for the 18-month analyses are compared to both the raw waste sample analyses and the treated, 28-day cured sample analyses. Percent reductions for each of the sample leach periods have also been included. Additional long-term (18-month) weathering studies from exposed monoliths of the STC-treated waste are discussed in the STC TER.

In all but three cases, the TCLP extracts of the 6-month cured samples showed an average increase in contaminant concentration of 79 percent from the 28-day sample leachates. Arsenic concentrations in Batches 4 and 5 were slightly lower in the 6-month tests; however, high analytical variability for these two batches indicates that the arsenic content in the leachate of the 6-month cured samples were similar to that of the 28-day cured sample leachate. The TCLP leachate of the 18-month cured samples for arsenic showed slight decreases from the 28-day and 6-month leachate concentrations. Percent reductions improved over the 18-month

Table B-15. Petrographic Analysis of STC-Treated Wastes

	Treated Wastes (Batches)					
Characteristics	**RM**	**1**	**1-QC**	**3**	**4**	**5**
Binder distribution	Uniform	Nonuniform	Nonuniform	Uniform	Uniform	Uniform
Consolidation	Well consolidated	Under consolidated	Well consolidated	Well consolidated	Well consolidated	Well consolidated
Hardness	Moderately hard	Moderately soft	Soft	Moderately soft	Moderately soft	Moderately soft
Bond	Moderately tight	Moderately tight	Moderately tight	Moderately tight	Moderately tight	Moderately tight
Air content (estimated)	5% to 7%	No estimate made	5% to 7%	3% to 5%	3% to 5%	3% to 5%
Microcracking	None	Minor	None	Minor	None	None
Phases present in binder	Calcium hydroxide Black pigment Isotropic glass Portland cement	Calcium hydroxide Black pigment Isotropic glass Portland cement	Calcium hydroxide Black pigment Isotropic glass Portland cement	Calcium hydroxide Black pigment Isotropic glass Portland cement	Calcium hydroxide Black pigment Isotropic glass Portland cement	Calcium hydroxide Black pigment Isotropic glass Portland cement
Soil constituents	Quartz, microcline; No oily clumps	Quartz, plagioclase feldspar, potassium feldspar, hornblende, clay, biotite, wood fragments, misc. organic debris, paper	Quartz, plagioclase feldspar, potassium feldspar, hornblende, clay, biotite, wood fragments, misc. organic debris, paper	Quartz, plagioclase feldspar, potassium feldspar, hornblende, clay, biotite, wood fragments, misc. organic debris, paper	Quartz, plagioclase feldspar, potassium feldspar, hornblende, clay, biotite, wood fragments, misc. organic debris, paper	Quartz, plagioclase feldspar, potassium feldspar, hornblende, clay, biotite, wood fragments, misc. organic debris, paper

RM = Solidified reagent mixture

Table B-16. Abundance of Mineralogic Phases in X-ray Diffraction Analysis of Raw and Treated Wastes

Mineralogic Phases	Raw Waste (Batch)	Treated Wastes (Batches)				
	1	RM	1	3	4	5
Quartz	Major	Major	Major	Major	Major	Major
Plagioclase Oligoclase	Major	ND	Major	Major	Major	Major
Potassium Feldspars Microcline Orthoclase	 Minor Minor	 Major Trace	 Minor Minor	 Minor Minor	 Minor Minor	 Minor Minor
Portlandite	ND	Minor	Minor	Minor	Minor	Minor
Hornblende	Minor	ND	Trace	Trace	Trace	ND
Illite or Biotite	Trace	ND	Trace	Trace	Trace	Trace
Ettringite	ND	Trace[a]	Trace	Trace	Trace	Trace

ND = Not detected

RM = Solidified reagent mixture

a = Gypsum may also be present in this sample.

Table B-17. Long-Term Test Results

Constituent	Batch	Raw Waste[a] (ppm)	Treated Waste (ppm)			Percent Reduction[b,c]		
			28 - day[a]	6 - month[a]	18 - month[c]	28 - day	6 - month	18 - month
Arsenic - TCLP	1	1.82 ± 0.47	0.09 ± 0.06	0.24 ± 0.07	0.07 ± 0.01	92	77	93
	3	1.06 ± 0.23	0.10 ± 0.03	0.26 ± 0.03	0.11 ± 0.09	83	56	82
	4	2.40 ± 0.60	0.88 ± 0.15	0.61 ± 0.17	0.18 ± 0.04	35	55	86
	5	3.33 ± 0.33	0.55 ± 0.10	0.47 ± 0.14	0.17 ± 0.02	71	76	91
Chromium - TCLP	1	0.13 ± 0.09	0.25 ± 0.01	0.28 ± 0.01	0.36 ± 0.08	-230	-280	-380
	3	<0.05	0.19 ± 0.01	0.25 ± 0.01	0.29 ± 0.04	NC	NC	NC
	4	0.10 ± 0.06	0.28 ± 0.01	0.51 ± 0.08	1.19 ± 0.09	-390	-810	-2,000
	5	0.27 ± 0.05	0.32 ± 0.03	0.63 ± 0.04	1.06 ± 0.16	-110	-310	-580
Copper - TCLP	1	3.42 ± 1.16	0.09 ± 0.01	0.12 ± 0.01	0.36 ± 0.17	95	94	81
	3	1.38 ± 0.15	0.08 ± 0.01	0.14 ± 0.02	0.14 ± 0.04	90	82	82
	4	6.53 ± 1.11	0.10 ± 0.01	0.25 ± 0.01	0.90 ± 0.29	97	93	75
	5	9.43 ± 1.40	0.06 ± 0.01	0.17 ± 0.05	1.43 ± 0.35	99	97	74

Table B-17. Long-Term Test Results (continued)

Constituent	Batch	Raw Waste[a] (ppm)	Treated Waste (ppm)			Percent Reduction[b,c]		
			28 - day[a]	6 - month[a]	18 - month[e]	28 - day	6 - month	18 - month
PCP - TWA[d]	1	2,350 ± 660	120 ± 40	100 ± 30	30 ± 10	91	92	98
	3	1,980 ± 270	90 ± 30	100 ± 20	30 ± 10	92	91	97
	4	7,700 ± 1,080	120 ± 40	370 ± 90	100 ± 3	97	91	98
	5	8,320 ± 1,440	220 ± 150	790 ± 420	410 ± 530	95	83	91

Arsenic and PCP were target analytes for treatment for this technology demonstration; chromium and copper were not.

NC = Not calculable

a = Results reported as the mean and standard deviation of six or more samples.

b = Percent Reduction $= \left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$

The low end of the percent reduction range was calculated by subtracting the standard deviation from the raw waste mean and adding the standard deviation to the treated waste mean to produce a worst-case value. The high end of the percent reduction range was calculated by adding the standard deviation to the raw waste mean and subtracting the standard deviation from the treated waste mean to produce a best-case value.

c = The additives ratio is the weight of additives, including water of hydration, divided by the weight of raw wastes. Values are 0.761, 0.764, 0.776, and 0.746 for Batches 1, 3, 4, and 5, respectively.

d = Estimated average concentrations using twice the detection limit for non-detected analyses.

e = Results reported as the mean and standard deviation of four samples.

period to range from 82 to 93 percent.

Chromium concentrations in the leachate of the 18-month cured samples showed slight to moderate increases with time, resulting in even greater negative percent reductions. Copper also showed very slight to moderate increases in TCLP-extract concentrations over time. Average percent reductions for copper dropped from 96 percent reduction after the initial 28-day curing period to 78 percent reduction after 18 months.

TWA of PCP after the 6-month period showed greater extractable concentrations for Batches 4 and 5 than after the initial 28-day period. Extractable concentrations of PCP generally remained consistent for Batches 1 and 2 over this time period. The 18-month analyses showed decreased concentrations of PCP in the treated waste; however, Batch 5 continued to show considerable analytical variability. Percent reductions following the 18-month period averaged 96 percent.

Table B-18 shows additional long-term ion-speciation analyses for chromium (VI) relative to total chromium in both raw and treated waste TCLP-Distilled Water extracts for Batch 5. The wastes were analyzed 8 months after the demonstration, revealing greater leachable quantities for both chromium (VI) and total chromium in the treated waste. The 8-month leachate contained approximately four times the quantity of total chromium compared to the 28-day TCLP-Distilled Water leachate, and almost three times as much total chromium as the initial raw waste sample, again indicating that STC's solidification/stabilization treatment process does not reduce the leaching of total chromium over the long term. Increased quantities of the ion-species chromium (VI) in the 8-month leachate compared to the raw waste values indicate that STC's treatment process may result in the oxidation of chromium, thereby rendering it more mobile. The long-term results are, however, still within the federal regulatory threshold level for chromium.

The physical strength of the STC-treated waste was evaluated after 18 months using the unconfined compressive strength (UCS) test. Results reported in Table B-19 show an average increase in strength of 71 percent over the 18-month period. Additional long-term analyses scheduled for 36 months following the demonstration will include solidification monitoring using unconfined compressive strength measurements and petrographic analyses as well as stabilization monitoring using chemical and leach tests. The final results for the long-term monitoring will be available from EPA upon completion.

Conclusions

The STC immobilization technology reduced the short-term mobility and leachability of arsenic and copper as measured by the TCLP and the TCLP-Distilled Water methods. The solidification/stabilization treatment process was also successful in reducing the mobility and potential leachability of PCP as measured by the TCLP-Distilled Water test and TWA. Leachability was not effectively reduced for chromium as measured by any of the leaching procedures, except possibly the ANS 16.1 test. However, chromium was not targeted for treatment in this demonstration and no specific additives were included to treat chromium. In addition, the CALWET leach test showed very inconsistent trends for all of the analytes.

Based on California state regulatory levels for legal disposal as nonhazardous waste in landfills, the STC treatment process did not consistently meet total (TTLC) or solubility (STLC) threshold limit concentration requirements. CALWET leach results were both below and above California's STLC levels for arsenic, copper, and PCP. TWA for chromium and copper were well below California's TTLC; however, TWA for arsenic and PCP were above California total threshold requirements for both the raw and treated wastes. Federal leach criteria could not be adequately evaluated since TCLP concentrations of arsenic, chromium, and PCP were below federal TCLP regulatory levels in both the raw and treated wastes.

Preliminary evidence suggests that the homogeneity and structural characteristics of the STC-treated waste would resist the normal effects of weathering. Low unconfined compressive strengths of the treated waste, although above minimum levels for disposal in landfills, were not sufficient for construction purposes. Additional tests would be needed to determine the appropriate reagent mixture necessary to meet construction requirements if desired. Initial

Table B-18. Long-Term (8-month) Chromium Analysis -- TCLP-Distilled Water (Batch 5)

Constituent	Raw Waste (ppm)	Treated Waste (ppm)
Chromium (VI)	<0.01 <0.01	0.15 0.18
Total Chromium	0.13 0.12	0.31 0.32

Table B-19. Long-Term Physical Tests

Batch	Unconfined Compressive Strength (psi)[a]	
	28-day	18-month
1	301 ± 162	958 ± 63
3	278 ± 20	763 ± 19
4	259 ± 65	1,017 ± 73
5	347 ± 65	1,375 ± 26

a = Results reported as mean and standard deviation of three samples.

6-month TCLP-extract and TWA showed increased concentrations of contaminants released from the treated waste. Eighteen-month analysis showed improved percent reductions for arsenic, averaging 88 percent reduction, and PCP averaging 96 percent reduction. Chromium and copper concentrations showed slight to moderate increases in the TCLP-extracts over time. Unconfined comprehensive strengths increased an average of 71 percent. The long-term stabilization and solidification effectiveness of the STC immobilization technology must still be monitored and assessed at the end of the planned 3-year period.

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Appendix C

Case Studies

Appendix C

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Appendix C

Case Studies

Introduction

This appendix summarizes case studies on the use and performance of Silicate Technology Corporation's(STC's)immobilizationtechnology. The information available for these case studies pertains mainly to detailed analytical data obtained from preliminary bench-scale treatability studies. The Tacoma Tar Pits case study represents both a bench- and pilot-scale treatability study, whereas the remaining four are bench-scale treatability studies. The bench-scale studies relating to the Tacoma Tar Pits, Purity Oil, and Kaiser Steel sites were performed in conjunction with the SITE demonstration program. Very little information was provided pertaining to system performance or costs. The following five case studies are summarized in this appendix:

Case Study	Facility and Location
C-1	Tacoma Tar Pits, Tacoma, Washington
C-2	Purity Oil Sales Site, Fresno, California
C-3	Kaiser Steel Corporation, Fontana, California
C-4	Brown Battery Breaking Superfund Site, Reading, Pennsylvania
C-5	Lion Oil Refinery, El Dorado, Arkansas

Case Study C-1

Tacoma Tar Pits

Tacoma, Washington

The Tacoma Tar Pits, Joseph Simon and Sons, Inc., site in Tacoma, Washington was initially considered as a potential demonstration site for evaluating STC's solidification/stabilization technology under the Superfund Innovative Technology Evaluation (SITE) program. This site covers approximately 30 acres and is located between the Puyallup River, the City Waterway, and Wheeler-Osgood Waterway in a predominantly industrial area of Tacoma, Washington. The area of sediment deposited as the Puyallup River delta is interfingered with marine sediments of Commencement Bay. These sediments form a tidal marsh/tidal flat with shallow, meandering streams.

Industrialization of the site and surrounding area began as early as the turn of the century, resulting in fill and dredge activity to develop the area for construction. A variety of industries have occupied the area, including railroad (Burlington Northern and Union Pacific) and meat packing operations. In 1924 a coal gasification plant was built on the site and operated by a number of entities. Construction of a natural gas pipeline to Tacoma in 1956 rendered the gasification plant obsolete. Waste tar containment structures were left in place below ground when the plant was demolished in 1965-1966. Since 1967, Joseph Simon and Sons, Inc., a metal recycler, has operated at the site.

The primary sources of contaminants at the site were tars from the old coal gasification plant as well as metals and organics (including PCBs) from the battery and transformer scrapping and automobile shredding by Joseph Simon and Sons, Inc. To a lesser degree, run-off from the meat processing facility and railroad facilities may have also affected the site.

Historical photographs indicate that coal tars once covered most of the southern and western portions of the site; however, recent access to coal tars has only been at the residual tar pit, tar boils, and the north and south ponds. Most of the area between the ponds at the far western side of the site and the tar pit in the southeastern portion of the site has been covered with shredded automobile interiors (auto fluff).

Typically, concentrated contaminants were present at the ponds as a non-aqueous phase liquid (NAPL) that had a strong creosote odor and were predominantly polycyclic aromatic hydrocarbons (PAH). Hazardous constituents present in the coal tars at the site included benzene, toluene, xylene, styrene, phenols, naphthalenes, dibenzofuran, methylene chloride, and chloroform. In addition to these, metals such as lead, arsenic, cadmium, aluminum, iron, chromium, and zinc were present in elevated concentrations in the auto fluff and subsurface soils.

The auto fluff covered much of the original tar pit and apparently underlies the north and south ponds. Auto fluff material consisted of shredded automobile interiors and had the texture and appearance of a silty-sandy soil mixed with metal fragments, shredded foam, rubber, wire, plastic, ceramic fragments, and other unidentifiable objects. Typically contaminants in the auto fluff included heavy metals and PCBs.

The most heavily contaminated areas of the site included those covered by auto fluff, the residual tar pit, tar pit boils, and the north and south ponds. During a preliminary sampling visit in October 1988, the north and south ponds both contained water. The substrate of the

ponds consisted of a tarry sediment mixed with pieces of auto fluff. Disturbance of the sediments produced an upwelling of concentrated NAPL from the pond bottom. The NAPL may have been mixed with animal process waste from the adjoining meat processing property as indicated by the fatty coating on sediments. Tar collected from the tar pit was much thicker than the pond sediment, and had the appearance of asphalt. The tar pit area also had a strong creosote odor, as did the tar boil area. Tar from the tar boil area was very thick, viscous, and often mixed with a variety of metal, ceramic debris, and some native soils.

In January 1989, STC conducted bench-scale treatability testing for the Tacoma Tar Pits site on wastes from the tar pit, the tar boils, the north and south ponds and the auto fluff areas. EPA's SITE contractor (PRC) performed sampling and analysis, including Toxicity Characteristic Leaching Procedure (TCLP), TCLP-Cage, Extraction Procedure (EP), and total waste analysis (TWA). Results for the chemical analyses of volatile and semivolatile organics as well as metals for both the raw and treated wastes are presented in Tables C-1-1 through C-1-5. Percent reductions were calculated by using 0.6 as the "additives ratio" for all reagents added during treatment, excluding water. The additives ratio was used to calculate the percent reduction using the following formula:

$$\textit{Percent Reduction} = \left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$$

In general, STC's treatment process yielded reductions in TCLP leachate concentrations for up to five volatile organics, up to eleven semivolatile organics, and up to seven metals from the combined sites at the Tacoma Tar Pits site. The greatest percent reductions for volatile organics included benzene, styrene, toluene, and total xylenes. However, the treatability testing was not conducted in a manner to capture and quantify volatile organics that may have been lost due to mixing during the treatment process and curing. Semivolatile organics that showed the greatest reductions in TCLP leachate concentrations included bis(2-ethylhexyl)phthalate, phenol, 2-methylphenol, 4-methylphenol, and 2,4-dimethylphenol. The greatest metal reductions were observed for zinc, lead, nickel, copper, and cadmium.

EP yielded reductions in leachate concentrations for up to ten semivolatile organics and four metals. Volatile organics were not analyzed using this leach test method. Semivolatiles with the greatest leachate concentration reductions included 2-methylphenol, phenol, and 2,4-dimethylphenol. The greatest metal reductions in leachate concentrations were observed for zinc, nickel, lead, and copper.

Finally, TWA yielded reductions for up to 13 semivolatile organics, five volatile organics (volatiles may have been airstripped) and seven metals. The greatest percent reductions in semivolatile concentrations were observed for fluorene, and 2,4-dimethylphenol. Volatile organics, except for benzene, generally yielded percent reductions in total concentration of less than 60 percent. Copper yielded the greatest metal percent reduction based on TWA.

In October, 1990, a pilot-scale field study was also performed by STC at the Tacoma Tar Pits site. The field study included treatment of 37 batches, including 27 different blends, 9 duplicates, and 1 blank batch. Three different wastes (tar, auto fluff, and contaminated soil) were treated at low, medium, and high reagent dosages (approximately 15%, 25%, and 30% on a dry weight basis at 60°C) for a total of 27 test batches.

Table C-1-6 shows the actual STC treated waste composition, including moisture content. These waste blends were developed during a second bench-scale study conducted prior to the pilot-scale field demonstration. Representative samples of auto fluff, tar, and soil were excavated. The auto fluff and soil were passed through a power screen for rough size fractionation and a secondary screening step for size classification. Auto fluff particles not passing through the screen were shredded and added to the mixture

Table C-1-1. Treatability Test Results for Raw and Treated Wastes from the Tacoma Tar Pits (Tar Pit)

Analyte	TCLP			EP Toxicity			TWA		
	Raw Waste (ppm)[a]	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]
Acenaphthene	0.027	0.018	-6	0.027	0.018	-5.7	533	187	44
Acenaphthylene	0.429	0.250	7	0.248	0.257	-65.8	4,630	1,427	51
Anthracene	0.021	0.012	10	0.020	0.055	-331.7	2,480	748	52
Dibenzofuran	0.072	0.038	16	0.050	0.036	-14.0	615	386	-0.4
Fluorene	0.119	0.094	-27	0.081	0.099	-94.5	3,980	1,210	51
2-Methylnaphthalene	2.655	2.13	-28	1.47	0.861	6.3	15,400	9,400	2
Naphthalene	4.90	4.26	-39	4.32	1.94	28.1	15,700	5,720	42
Phenanthrene	0.088	0.079	-43	0.065	0.074	-80.6	9,100	2,770	51
2,4-Dimethylphenol	1.605	0.696	31	1.67	0.080	92.4	87.6	42.7	22
2-Methylphenol	1.330	0.457	45	1.49	0.135	85.5	40.6	11.7	54
4-Methylphenol	2.815	0.832	53	3.08	0.170	91.2	83.3	23.5	55
Phenol	2.185	0.564	59	2.42	0.202	86.6	56.5	17.8	50
Benzene	2.76	0.41	76	NA	NA	NC	76.6	46.5	3
Toluene	7.54	1.17	75	NA	NA	NC	177	145	-31
Xylenes(total)	0.636	0.345	13	NA	NA	NC	116	125	-72
Lead	<0.04	<0.04	NC	<0.04	<0.04	NC	39.1	<20	>18
Chromium	<0.02	<0.02	NC	<0.02	<0.02	NC	7.7	8.62	-79
Copper	<0.02	<0.02	NC	<0.02	<0.02	NC	37.2	<10	>57
Zinc	0.278	<0.02	>89	0.518	<0.02	>93.8	82.4	21.3	59

NA = Not analyzed
NC = Not calculable
a = Results reported as mean of duplicate samples.

b = Percent Reduction $\left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$

The additives ratio is the weight of the additives, excluding water, divided by the weight of the waste treated, and equals 0.6.

Table C-1-2. Treatability Test Results for Raw and Treated Wastes from the Tacoma Tar Pits (Tar Boils)

Analyte	TCLP			EP Toxicity			TWA		
	Raw Waste (ppm)[a]	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]
Acenaphthene	0.038	0.027	-14	0.024	0.032	-117	587	282	23
Acenaphthylene	0.623	0.576	-48	0.554	0.437	-26	5,440	2,131	37
Anthracene	0.023	0.018	-25	0.017	0.015	-39	2,820	1,100	38
Dibenzofuran	0.052	0.048	-47	0.043	0.055	-105	676	581	-38
Fluorene	0.139	0.123	-42	0.082	0.150	-194	48,300	1,500	95
2-Methylnaphthalene	2.110	2.540	-93	1.770	1.890	-71	13,600	10,500	-24
Naphthalene	3.90	5.56	-128	2.520	4.510	-186	14,100	6,240	29
Phenanthrene	0.140	0.097	-11	0.080	0.091	-83	10,200	4,400	31
2,4-Dimethylphenol	0.220	0.567	-313	0.178	0.116	-4	82.5	809	-1,469
2-Methylphenol	0.208	0.538	-314	0.118	0.340	-361	49.8	24.2	22
4-Methylphenol	0.398	1.070	-330	0.222	0.524	-278	124	43.9	43
Phenol	0.160	0.844	-746	0.121	0.535	-607	96	50.2	16
Benzene	0.485	0.427	-41	NA	NA	NC	45.5	33.2	-17
Ethylbenzene	0.120	0.093	-25	NA	NA	NC	15.6	12.0	-23
Styrene	0.217	<0.005	96	NA	NA	NC	89.5	71.7	-28
Toluene	1.380	0.630	27	NA	NA	NC	112	76.7	-10
Xylenes(total)	0.249	0.190	-22	NA	NA	NC	79.4	67.2	-35
Arsenic	0.047	<0.04	-38	<0.04	<0.04	NC	19.4	NA	NC

Table C-1-2. Treatability Test Results for Raw and Treated Wastes from the Tacoma Tar Pits (Tar Boils) (Continued)

Analyte	TCLP			EP Toxicity			TWA		
	Raw Waste (ppm)[a]	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]
Lead	0.250	<0.04	74	0.078	<0.04	>18	128	<20	75
Chromium	<0.02	<0.02	NC	<0.02	<0.02	NC	156	75.9	22
Copper	0.030	<0.02	-7	0.137	<0.02	>77	350	<10	95
Nickel	<0.02	<0.02	NC	<0.02	<0.02	NC	133	66	21
Zinc	0.627	<0.02	95	0.481	0.158	47	227	144	-2

NA = *Not analyzed*
NC = *Not calculable*
a = *Results reported as mean of duplicate samples.*

b = *Percent Reduction* $\left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$

The additives ratio is the weight of the additives, excluding water, divided by the weight of the waste treated, and equals 0.6.

Table C-1-3. Treatability Test Results for Raw and Treated Wastes from the Tacoma Tar Pits (North Pond)

Analyte	TCLP			EP Toxicity			TWA		
	Raw Waste (ppm)[a]	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]
Acenaphthene	0.064	0.019	53	0.039	<0.004	>84	210	182	-39
Acenaphthylene	0.234	0.044	70	0.249	0.069	56	744	398	14
Anthracene	0.018	<0.008	>28	<0.01	<0.004	NC	406	248	2
Bis(2-ethylhexyl)phthalate	0.903	<0.008	>86	<0.01	<0.004	NC	<10	<2	NC
Dibenzofuran	0.026	0.009	46	0.028	<0.004	>77	110	127	-85
Fluorene	0.083	0.027	47	0.059	<0.004	>89	572	420	-18
2-Methylnaphthalene	0.999	0.540	14	1.680	0.585	44	2,470	2,390	-55
Naphthalene	2.685	0.775	54	3.630	1.060	53	2,350	1,330	9
Phenanthrene	0.073	0.018	62	0.039	<0.004	>84	1,510	1,030	-9
2,4-Dimethylphenol	0.647	0.038	91	0.599	0.063	83	16.1	5.44	46
2-Methylphenol	0.242	0.023	85	0.224	0.036	74	<10	3.19	NC
Phenol	0.069	<0.004	>91	0.079	0.032	35	<10	6.68	NC
Benzene	1.063	0.084	87	NA	NA	NC	23.2	9.01	38
Ethylbenzene	0.421	0.141	46	NA	NA	NC	50.1	35.3	-13
Styrene	0.144	0.036	60	NA	NA	NC	14.4	8.58	5
Toluene	1.370	0.437	49	NA	NA	NC	62.1	30.8	21
Xylenes(total)	0.531	0.144	57	NA	NA	NC	57.8	47.8	-32
Arsenic	0.055	<0.04	>-17	<0.04	<0.04	NC	5.04	NA	NC

Table C-1-3. Treatability Test Results for Raw and Treated Wastes from the Tacoma Tar Pits (North Pond) (Continued)

Analyte	TCLP			EP Toxicity			TWA		
	Raw Waste (ppm)[a]	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]
Cadmium	<0.005	<0.005	NC	<0.005	<0.005	NC	5.09	4.48	-41
Lead	0.664	0.04	90	0.083	0.04	23	86.7	<20	63
Chromium	<0.02	<0.02	NC	<0.02	<0.02	NC	9.8	22.1	-261
Copper	<0.02	<0.02	NC	<0.02	<0.02	NC	198	<10	92
Nickel	0.270	<0.02	>88	0.335	<0.02	>90	14.4	8.01	11
Zinc	4.180	<0.02	>99	5.220	<0.02	>99	439	239	13

NA = *Not analyzed*
NC = *Not calculable*
a = *Results reported as mean of duplicate samples.*

b = *Percent Reduction* $\left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$

The additives ratio is the weight of the additives, excluding water, divided by the weight of the waste treated, and equals 0.6.

Table C-1-4. Treatability Test Results for Raw and Treated Wastes from the Tacoma Tar Pits (South Pond)

Analyte	TCLP			EP Toxicity			TWA		
	Raw Waste (ppm)[a]	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]
Acenaphthene	0.133	0.101	-22	0.082	0.107	-109	1660	541	48
Acenaphthylene	0.328	0.123	40	0.145	0.124	-37	2800	588	66
Anthracene	0.023	0.008	41	0.012	0.006	26	1930	617	49
Dibenzofuran	0.047	0.027	8	0.037	0.031	-34	492	230	25
Fluorene	0.124	0.078	-0.3	0.069	0.088	-104	4180	750	71
2-Methylnaphthalene	2.065	1.560	-21	2.210	0.776	44	12000	4450	41
Naphthalene	4.705	3.460	-18	5.370	2.360	30	12600	2930	63
Phenanthrene	0.122	0.058	25	0.060	0.056	-50	8570	1910	64
2,4-Dimethylphenol	0.665	0.110	74	0.664	0.124	70	39	<2	92
2-Methylphenol	0.333	0.041	80	0.259	<0.004	98	<20.8	1.73	NC
4-Methylphenol	0.562	0.099	72	0.049	0.043	-42	<20	<2.0	NC
Phenol	0.057	<0.004	89	0.082	0.013	74	<20	<2.0	NC
Benzene	2.005	0.044	97	NA	NA	NC	77.3	17.9	63
Ethylbenzene	0.327	1.000	-390	NA	NA	NC	141	80.8	8
Styrene	0.396	<0.005	98	NA	NA	NC	40.1	11.8	53
Toluene	8.010	0.304	94	NA	NA	NC	233	67.6	54
Xylenes(total)	0.575	0.114	68	NA	NA	NC	205	69.1	46
Lead	0.069	<0.04	7	0.040	<0.040	NC	83	<20	-563

Table C-1-4. Treatability Test Results for Raw and Treated Wastes from the Tacoma Tar Pits (South Pond) (Continued)

Analyte	TCLP			EP Toxicity			TWA		
	Raw Waste (ppm)[a]	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]
Copper	<0.02	<0.02	NC	<0.02	<0.02	NC	31.6	<10	49
Nickel	0.085	<0.02	62	0.13	<0.02	75	29.7	7.68	59
Zinc	1.019	<0.02	97	1.10	<0.02	97	184	150	-30

NA = *Not analyzed*
NC = *Not calculable*
a = *Results reported as mean of duplicate samples.*

b = *Percent Reduction* $\left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$

The additives ratio is the weight of the additives, excluding water, divided by the weight of the waste treated, and equals 0.6.

Table C-1-5. Treatability Test Results for Raw and Treated Wastes from the Tacoma Tar Pits (Auto Fluff)

Constituent	TCLP			EP Toxicity			TWA		
	Raw Waste (ppm)[a]	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]	Raw Waste (ppm)	Treated Waste (ppm)	% Reduction[b]
Toluene	0.364	0.023	90	NA	NA	NC	<0.5	<5.0	NC
Arsenic	<0.04	<0.04	NC	<.04	<.04	NC	25.5	<25.0	>(-57)
Cadmium	0.548	<0.005	99	0.46	<0.005	98	38.2	12.9	46
Lead	8.275	<0.04	99	2.68	<.04	98	3,200	445	78
Chromium	<0.02	<0.02	NC	<0.02	<0.02	NC	168	47.2	55
Copper	0.89	<0.02	96	0.52	<0.02	94	1,800	99.6	91
Nickel	1.57	0.082	92	1.57	<0.02	98	269	56.5	66
Zinc	71.8	0.196	100	110	<0.02	100	7,240	1,740	62

NA = *Not analyzed*
NC = *Not calculable*
a = *Results reported as mean of duplicate samples.*

b = *Percent Reduction* $\left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$

The additives ratio is the weight of the additives, excluding water, divided by the weight of the waste treated, and equals 0.6.

Table C-1-6. STC-Treated Waste Composition

Sample	Soil % of Dry Wt.	Fluff % of Dry Wt.	Tar % of Dry Wt.	S-4 Wt. %	P-27 Wt. %	Moisture Content Wt. %
I-L	67.8	0	0	2.7	13.6	15.9
I-MA	58.6	0	0	2.3	23.4	15.7
I-H	52.0	0	0	2.1	31.2	14.7
II-L	46.2	19.8	0	2.6	13.2	18.2
II-M-1	40.2	17.2	0	2.3	23.0	17.3
II-M-2	38.9	16.6	0	2.2	22.3	20.0
II-M-3	41.0	17.5	0	2.3	23.4	15.8
II-M-4	39.9	17.1	0	2.3	22.8	17.9
II-H	34.6	14.8	0	2.0	29.6	19.0
III-L	25.9	38.9	0	2.5	12.9	19.8
III-M	21.8	32.8	0	2.2	21.8	21.4
III-H	19.7	29.6	0	2.0	29.6	19.1
IV-L	58.9	0	6.5	2.6	13.1	18.9
IV-M-1A	51.0	0	5.6	2.2	22.6	18.6
IV-M-2	50.5	0	5.6	2.2	22.4	19.3
IV-M-3	51.5	0	5.7	2.2	22.8	17.8
IV-M-4	51.5	0	5.7	2.2	22.8	17.8
IV-H	45.2	0	5.0	1.9	30.1	17.8
V-L	39.8	19.9	6.6	2.6	13.2	17.9
V-M-1	33.0	16.5	5.5	2.2	22.2	20.8
V-M-2	33.4	16.7	5.5	2.2	22.3	19.9
V-M-3	31.8	15.9	5.3	2.1	21.1	23.8
V-M-4	33.0	16.4	5.5	2.1	22.0	21.0
V-H	29.3	14.7	4.9	1.9	29.3	19.9
VI-LA	13.5	37.0	6.2	2.5	12.3	28.5
VI-M	16.1	32.4	5.4	2.1	21.5	22.5
VI-H	14.4	28.8	4.8	1.9	28.8	21.3
VII-L	50.1	0	12.5	2.5	12.5	22.4
VII-M	44.0	0	10.9	2.2	21.9	21.0
VII-H	38.0	0	9.5	1.9	28.5	22.1

Table C-1-6. STC-Treated Waste Composition (continued)

Sample	Soil % of Dry Wt.	Fluff % of Dry Wt.	Tar % of Dry Wt.	S-4 Wt. %	P-27 Wt. %	Moisture Content Wt. %
VIII-L	31.2	18.7	12.4	2.4	12.4	22.9
VIII-M	26.7	16.0	10.6	2.1	21.4	23.2
VIII-H	28.7	14.2	9.5	1.9	28.4	17.3
IX-L	12.0	36.0	12.0	2.4	12.0	25.6
IX-M	10.7	32.1	10.7	2.1	21.4	23.0
IX-HA	9.3	28.0	9.3	1.8	28.0	23.6
BLANK-M	62.9	0	0	2.5	25.1	9.5

to produce the final blends. The blended piles of contaminated waste were sampled and analyzed for chemical contaminants including benzene, lead, PCBs, and PAHs. Table C-1-7 presents the analytical results for the raw waste blends. TCLP was not conducted for the raw waste blends of this pilot-scale field study. Approximately 1/2-cubic-yard blocks of treated waste were allowed to cure in wooden forms for 28 days. Sampling procedures, as well as physical and chemical analyses are described in STC's Batch Plant Demonstration Sampling and Analysis Plan.

Results of TCLP analyses of the treated wastes are shown in Table C-1-8. These results indicate that the STC treatment process was generally successful in stabilizing the various soil blends for all contaminants (PCBs, PAHs, and lead) except benzene; however direct comparisons between raw and treated wastes cannot be made because the raw waste was not evaluated by TCLP methods. All lead values were below detection limits of 20 μg/L. All but three of the PCB results were below the detection limits. Three samples did indicate leachable PCBs; two were above the record of decision (ROD) levels for ground water at the site boundary (0.2 μg/L). In addition, one PCB detection was from a replicated blend that had no PCBs detected in the other samples. All PAH results were at least an order of magnitude below the ROD limits for ground water at the site boundary and many were below detection. The TCLP data indicate that the STC stabilized materials meet ROD criteria for leachable lead, PAHs, and PCBs throughout the range of blends tested in the field study. The only contaminant that appeared to leach at significant levels was benzene. The leachable benzene concentration varied from negligible amounts in samples that did not contain tarry material to an average of approximately 5 times the ROD established limits for blends containing 20 percent dry weight tarry material.

Field blank samples were also chemically tested to determine if leachable contaminants were contributed by sources other than the raw waste materials. The results of the TCLP analysis of the field blank indicated that the vendor ingredients did not contribute to leachable contamination.

Statistical analyses of the chemical data reported by STC indicate that the STC process could successfully stabilize the waste materials for all contaminants (PCBs, PAHs, and lead) except benzene at the Tacoma Tar Pits site with a 95 percent confidence level. The analyses showed that the level of additive did not have a significant effect on the chemical stabilization of the waste material analyzed. The level of fluff in the stabilized material also had no effect on the chemical stabilization. Therefore, it was concluded that fluff concentrations up to 60 percent (dry weight) in the feed blend could be successfully stabilized within the range of additive and tarry material tested in the pilot-scale field study. The statistical analyses also indicated that up to 9 percent tarry material could be stabilized with 95 percent confidence to below the ROD criteria for benzene in ground water at the site boundary. Dilution of benzene prior to reaching the site boundary is likely to result in benzene concentrations that are one-fifth of the original concentrations based on the site hydrogeologic conditions. Therefore, it appears that the entire range of tarry material (up to 20 percent dry weight in the feed blank) is likely to be successfully stabilized by the STC treatment process.

Table C-1-9 presents results for physical analyses including hydraulic conductivity, bulk density, durability, and unconfined compressive strength. All but three of the hydraulic conductivities were so low that they could not be measured. Table C-1-9 designates the unmeasurable hydraulic conductivities with a "low" identifier. A statistical evaluation was not performed on the STC hydraulic conductivity results since all of the results achieved the established criteria of 10^{-7} cm/sec. Bulk densities of the STC stabilized materials ranged from 1.6 to 2.0 g/cm^3, while durability measurements ranged from -2 to 3 percent loss in mass. Unconfined compressive strength results ranged from 114 to 1,082 psi, easily exceeding the minimum hazardous waste landfill criteria of 50 psi.

Table C-1-7. STC Raw Waste Analytical Results

Sample	Benzene (mg/kg)	Lead (mg/kg)	PCBs[a](mg/kg)			PAHs[b] (mg/kg)
			AR1242	AR1254	AR1260	
I-L	ND	533	1.1	ND	12.0	27.5
I-M	0.22	546	1.4	1.3	10.0	15.7
I-MA	0.10	668	2.2	ND	18.0	2.1
I-H	0.04	613	2.0	ND	18.0	27.9
II-L	ND	1,650	0.6	0.4	6.9	142
II-M-1	ND	1,830	7.9	5.0	19.0	11.7
II-M-2	0.10	2,400	7.7	3.1	11.0	3.3
II-M-3	0.04	1,470	7.8	2.9	15.0	17.2
II-M-4	0.32	2,460	7.1	4.2	13.0	4.5
II-H	0.10	1,710	26.0	21.0	19.0	11.5
III-L	0.12	3,170	14.0	9.8	16.0	9.8
III-M	ND	14,500	6.1	2.2	7.4	29.1
III-H	0.19	2,810	9.0	4.4	11.0	37.5
IV-L	4.8	497	ND	2.3	11.0	88.2
IV-L	5.3	477	---	---	---	134
IV-M	13	580	2.3	ND	12.0	72.8
IV-M-1	12	577	0.6	0.6	5.6	64.2
IV-M-2	10	588	1.9	1.2	14.0	72.9
IV-M-3	9.3	756	1.6	ND	13.0	134
IV-M-4	14	629	1.2	1.3	14.0	221
IV-H	14	583	1.2	2.0	9.0	134
V-L	14	2,300	12.0	3.2	23.0	72.6
V-M-1	9.5	2,020	7.0	4.4	12.0	97.4
V-M-2	12	1,690	5.9	3.2	10.0	93.2
V-M-3	8.1	1,890	7.7	8.0	12.0	130
V-M-4	9.6	2,140	8.4	5.1	16.0	101
V-H	22	3,140	17.0	4.9	12.0	62.5
VI-LA	8.9	3,380	13.0	7.4	14.0	80.9
VI-M	11	3,160	11.0	5.8	12.0	163

Table C-1-7. STC Raw Waste Analytical Results (continued)

Sample	Benzene (mg/kg)	Lead (mg/kg)	PCBs[a] (mg/kg)			PAHs[b] (mg/kg)
			AR1242	AR1254	AR1260	
VI-H	9.8	4,140	12.0	4.8	14.0	100
VII-L	22	459	0.6	1.4	6.8	230
VII-M	27	507	6.0	3.7	9.5	18.2
VII-H	24	687	2.8	2.4	18.0	191
VIII-L	21	1,730	12.0	4.7	15.0	173
VIII-M	17	2,170	3.6	3.0	5.5	115
VIII-H	19	1,700	5.4	3.9	8.7	214
IX-L	20	2,910	9.1	6.5	8.5	254
IX-M	15	3,110	21.0	16.0	19.0	151
IX-H	16	3,070	14.0	10.0	11.0	241
IX-HA	30	3,130	18.0	10.0	17.0	202
BLANK-M	ND	ND	ND	ND	ND	ND
DL	0.025-0.03	4	0.02-2.5	0.02-2.5	0.02-2.5	0.033-9.4

ND = Not detected
DL = Detection limits

a = TCMX spike ineffective in matrix, therefore, data were not flagged for low TCMX spike recovery.

b = Sum of six PAHs. One half detection value used for samples below detection.

Table C-1-8. TCLP Analytical Results for STC-Treated Wastes

Sample	Benzene (µg/L)	Lead (µg/L)	PCBs[a] (µg/L)			PAHs[b] (µg/L)
			AR1242	AR1254	AR1260	
I-L	2.1	ND	ND	ND	ND	0.08
I-MA	2.0	ND	ND	ND	0.18	0.09
I-H	2.0	ND	ND	ND	ND	0.06
II-L	1.1	ND	ND	ND	ND	0.07
II-M-1	1.3	ND	ND	ND	ND	0.20
II-M-2	1.6	ND	ND	ND	ND	0.10
II-M-3	0.76	ND	ND	ND	ND	0.12
II-M-4	1.5	ND	ND	ND	ND	ND
II-H	0.96	ND	ND	ND	ND	ND
III-L	0.55	ND	ND	ND	ND	ND
III-M	0.66	ND	ND	ND	ND	ND
III-H	0.79	ND	ND	ND	ND	ND
IV-L	68	ND	ND	ND	ND	ND
IV-M-1A	64	ND	ND	ND	ND	0.73
IV-M-2	28	ND	ND	ND	ND	0.10
IV-M-3	41	ND	ND	ND	0.38	0.63
IV-M-4	73	ND	ND	ND	ND	0.32
IV-H	88	ND	ND	ND	ND	ND
V-L	51	ND	ND	ND	ND	0.38
V-M-1	63	ND	ND	ND	ND	ND
V-M-2	49	ND	ND	ND	ND	ND
V-M-3	40	ND	ND	ND	ND	ND
V-M-4	66	ND	ND	ND	ND	0.41
V-H	10	ND	ND	ND	ND	ND
VI-LA	100	ND	ND	ND	ND	0.80
VI-M	86	ND	ND	ND	ND	0.67
VI-H	28	ND	ND	ND	ND	ND
VII-L	410	ND	ND	ND	ND	ND
VII-M	220	ND	ND	ND	ND	ND

Table C-1-8. TCLP for STC-Treated Wastes Analytical Results (continued)

Sample	Benzene (µg/L)	Lead (µg/L)	PCBs[a] (µg/L)			PAHs[b] (µg/L)
			AR1242	AR1254	AR1260	
VII-H	140	ND	ND	ND	ND	ND
VIII-L	190	ND	ND	ND	ND	0.69
VIII-M	130	ND	0.19	ND	0.24	2.13
VIII-H	170	ND	ND	ND	ND	1.85
IX-L	250	ND	ND	ND	ND	0.72
IX-M	190	ND	ND	ND	ND	0.89
IX-HA	210	ND	ND	ND	ND	ND
BLANK-M	ND	ND	ND	ND	ND	ND
DL	0.5	20	0.10-0.12	0.10-0.12	0.10-0.12	0.01-0.4

ND = Not detected
DL = Detection limits

a = TCMX spike ineffective in matrix, therefore, data were not flagged for low TCMX spike recovery.

b = Sum of six PAHs. One half detection value used for samples below detection.

Table C-1-9. Physical Test Results of STC-Treated Waste

Sample	Water Content		Saturation		Hydraulic Conductivity (cm/sec)	Durability				Bulk Density (g/cm^3)	Unconfined Compressive Strength (psi)
						Water Content		Volume Change (%)	Mass Change (%)		
	Before (%)	After (%)	Before (%)	After (%)		Initial (%)	Final (%)				
I-L	11	17	49	92	Low*	17	11	-0.80	0	1.97	788
I-MA	13	15	74	85	Low*	12	11	-1.69	-2	2.00	1,082
I-H	13	15	74	91	Low*	12	11	-0.79	1	2.02	729
II-L	15	20	62	84	Low*	19	13	-0.75	0	1.86	405
II-M-1	15	18	76	90	Low*	13	13	-1.67	-1	1.87	729
II-M-2	17	22	65	83	Low*	18	14	-1.64	0	1.89	729
II-M-3	14	17	66	88	Low*	14	12	-1.57	1	1.94	1,068
II-M-4	15	20	58	75	Low*	15	14	-0.78	-2	1.91	700
II-H	15	18	63	77	Low*	15	13	-1.55	1	1.92	644
III-L	20	24	62	76	Low*	27	24	-2.44	-1	1.78	375
III-M	18	23	69	87	Low*	19	16	-1.61	0	1.78	604
III-H	14	18	61	78	Low*	16	14	-0.83	1	1.83	618
IV-L	18	23	69	89	Low*	21	13	-0.44	0	1.86	332
IV-M-1A	14	18	57	73	Low*	15	12	-2.42	-2	1.91	983
IV-M-2	16	19	74	86	Low*	16	12	-1.61	1	1.89	1,026
IV-M-3	14	17	73	88	Low*	15	12	-1.61	1	1.91	997
IV-M-4	18	20	76	88	Low*	17	14	-3.10	-1	1.87	604
IV-H	13	17	63	82	Low*	27	24	-2.94	-2	1.94	944
V-L	26	31	79	93	Low*	21	15	-0.77	-2	1.71	283
V-M-1	19	24	67	86	Low*	19	15	-1.11	-1	1.81	439
V-M-2	20	25	70	89	Low*	17	15	-1.68	-1	1.83	398
V-M-3	18	25	66	92	Low*	19	15	-0.34	0	1.81	460

Table C-1-9. Physical Test Results of STC-Treated Waste (continued)

Sample	Water Content		Saturation		Hydraulic Conductivity (cm/sec)	Durability				Bulk Density (g/cm^3)	Unconfined Compressive Strength (psi)
						Water Content		Volume Change (%)	Mass Change (%)		
	Before (%)	After (%)	Before (%)	After (%)		Initial (%)	Final (%)				
V-M-4	20	23	76	88	Low*	18	14	-0.83	0	1.79	460
V-H	16	20	60	75	Low*	15	14	-2.29	0	1.87	722
VI-LA	25	33	68	86	2×10^{-8}	28	19	-0.87	0	1.65	120
VI-M	19	20	56	58	Low*	23	15	-1.63	3	1.73	447
VII-L	23	28	78	95	Low*	23	14	-2.46	0	1.75	256
VI-H	20	25	65	82	Low*	19	16	-2.52	0	1.78	454
VII-M	17	26	50	82	Low*	24	16	-0.82	-1	1.76	518
VII-H	18	22	59	73	Low*	19	15	-1.64	-1	1.81	707
VIII-L	27	32	72	85	1×10^{-8}	27	17	-2.68	-1	1.68	170
VIII-M	23	26	62	72	Low*	24	18	-3.94	0	1.71	483
VIII-H	22	26	70	83	Low*	23	18	-2.34	0	1.75	575
IX-L	24	37	52	81	5×10^{-8}	33	24	0.80	0	1.60	114
IX-M	27	31	77	89	Low*	26	18	-3.85	2	1.67	347
IX-HA	22	27	69	82	Low*	25	19	-1.53	2	1.68	575
BLANK-M	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.11	3,254

* = *Samples exhibited less flow than samples with measurable conductivity*

NA = *Not analyzed*

NOTE: Initial mass of durability sample was calculated from the initial wet weight of the durability sample, and the moisture content of a "control" sample. Accuracy of the mass loss (%) is dependent on similarity in the moisture contents of the sample.

Case Study C-2

Purity Oil Sales Site

Fresno, California

The Purity Oil Sales (POS) site in Fresno, California was selected for bench-scale treatability testing to determine the effectiveness of STC's solidification/stabilization technology on wastes from this site, and whether the POS site should be considered for a full-scale STC demonstration under the SITE program.

The POS site is located in Malaga, California, about 1/2-mile southeast of the Fresno city limits. The site is bounded by South Maple Avenue to the east, the North Central Irrigation Canal to the south, and the A.T. and S.F. Railroad to the west. The area outside the northern boundary consists of residential and commercial properties.

The site is an abandoned oil reprocessing facility operated mainly for recycling used motor oils from 1934 until 1975. The steps in the process involved settling out heavier solids, dewatering by heating, acidification, and filtering through a clay bed. The wastes produced during the process included acid sludge, wastewater, insoluble solids, and spent clay slurry that were disposed of on site. In addition, storage tanks existed on site with a nearby impoundment for collecting spills. Several unlined waste pits up to 10 feet deep were used during site operations for storage and disposal of waste materials. These waste pits were subsequently filled with soil and demolition debris consisting of concrete, bricks, steel, wood, and tires. Numerous surface spills of oily/tarry materials from oil reprocessing also occurred at the site prior to its closure.

Site contamination has resulted from surface spills, improper disposal practices, and possibly leaking storage tanks. Contamination attributable to past site activities has been detected in the ground water (on site and near off site), canal sediments, and on-site surface and subsurface soils. Chemical analyses indicated that the contaminated waste was acidic, and high in lead and certain organic compounds. Analytical results of subsurface boring samples indicated the waste contained toluene, benzene, polyaromatic hydrocarbons (PAHs), methylene chloride, phthalates, acetone, and other compounds. Pesticides were also detected in some of the waste pit areas. The wastes did not meet RCRA criteria for definition as a characteristic hazardous waste; however, the wastes did have concentrations of lead that exceeded the California Total Threshold Limit Concentration (TTLC) value for definition as a hazardous waste.

The waste samples were analyzed before and after treatment by the STC solidification/stabilization processes. The sampling and analyses were conducted in accordance with a Draft Preliminary Sampling Plan prepared for EPA's Office of Research and Development (U.S. EPA, 1989). The sampling plan detailed the sampling approach, laboratory procedures, and quality assurance and quality control procedures for the treatability studies.

EPA's SITE contractor (PRC) collected waste characterization samples and treatability samples at the POS site on September 26, 1989. Samples were obtained from a drum of contaminated material. The drum was filled with waste collected from soil horizon "B" as part of a removal action and was selected by the EPA remedial project manager at the site. Contaminated material was withdrawn from three different depths within the drum using a stainless-steel scoop. The material taken from the drum was then composited in a 10-gallon drum and split into several portions. One portion was sent to STC for treatment, and another portion was shipped to Engineering-Science, Inc. Berkeley, California (ESBL), for analysis. ESBL analyzed

the raw waste for a number of volatiles, semi-volatiles, metals, fluorides, asbestos, pesticides, and polychlorinated biphenyls (PCB). Analytical methods included a total waste analysis (TWA), the Toxicity Characteristic Leaching Procedure (TCLP), and the California Waste Extraction Test (CALWET).

After obtaining the analytical results from the raw waste, STC estimated the optimum reagent-to-waste ratios (by weight) to be used in the treatability studies, based on experience from previous testing of similar wastes. STC then treated the raw waste in four batches. Two batches were treated at the optimum reagent-to-waste ratio, one batch was treated at 50 percent of the optimum ratio, and another batch was treated at 150 percent of the optimum ratio. The treated wastes were cured for 28 days and a portion of each batch shipped to ESBL for analyses.

ESBL analyzed the treated wastes for the same set of constituents analyzed in the raw waste. The TCLP was performed on treated waste samples representing each of the three different reagent-to-waste ratios. The results of these analyses were used to verify the vendor's estimates for the optimum reagent concentrations.

Upon receiving the analytical results from the TCLP analyses of the treated waste, STC, in conjunction with the EPA SITE program manager, selected the reagent-to-waste ratio that would be used for additional TWA analyses. STC then sent additional wastes that had been treated at their chosen reagent-to-waste ratios to ESBL for analysis. Analytical methods included TWA and TCLP. These additional tests involved the same set of constituents analyzed in the previous tests.

The following discussion provides an interpretation of the analytical results from the testing performed on the raw waste and wastes treated by STC's solidification/stabilization process. The TCLP results were evaluated by calculating the percent reduction of organic and inorganic constituents that were achieved by the treatment process. The percent reduction was calculated by using an "additives ratio" for the treatment. The additives ratio is defined as the ratio of all reagents or cements added during treatment (not including water) to the amount of waste being treated. The additives ratio was used to calculate the percent reduction for organic and inorganic constituents using the following formula:

$$\textit{Percent Reduction} = \left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$$

Table C-2-1 presents the results of TCLP analyses of raw waste and waste treated by STC at three reagent-to-waste ratios (0.22, 0.42, and 0.62), plus TWA at the optimum reagent-to-waste ratio of 0.42. The table shows that the STC treatment process reduced the leachability of several constituents, including trichloroethylene, benzene, and five metals. No measures were taken to capture and quantify volatiles that may have been lost due to mixing and curing.

The results shown in Table C-2-1 are generally consistent across the different reagent-to-waste ratios for the treated waste and the duplicate analyses conducted on the samples of wastes treated at the optimum reagent-to-waste ratio. However, several constituents were associated with inconsistent trends (both positive and negative percent reductions) between the different treated wastes. These constituents included lead, toluene, and xylene.

Table C-2-1 also presents the results of total waste analysis for selected contaminants in the raw wastes and wastes treated by STC at the optimum reagent-to-waste ratio of 0.42 as determined by the TCLP analyses. The table shows that the STC process reduced the concentrations of some of the contaminants including cadmium, chromium, copper, lead, and zinc. Lower percent reductions were reported for benzene and trichloroethylene, and inconsistent percent reductions resulted for toluene and xylene.

Table C-2-1. Analytical Results for Purity Waste

Analyte: Cadmium	Raw Waste		Additives Ratio[d]	Treated Waste		Percent Reduction[e]
Analysis	(ppm)	Reporting Limits		(ppm)	Reporting Limits	
TWA	25[a]	1	0.42	16	1	9[c]
TCLP	0.32	0.01	0.22	0.14	0.01	47
			0.42	ND/ND[b]	0.01/0.01	>95/>95
			0.62	0.14	0.01	29

Analyte: Chromium	Raw Waste		Additives Ratio[d]	Treated Waste		Percent Reduction[e]
Analysis	(ppm)	Reporting Limits		(ppm)	Reporting Limits	
TWA	37	5	0.42	32	5	-23[c]
TCLP	0.16	0.05	0.22	ND	0.05	>62
			0.42	ND/ND[b]	0.05/0.05	>56/>56
			0.62	0.053	0.05	13

Analyte: Copper	Raw Waste		Additives Ratio[d]	Treated Waste		Percent Reduction[e]
Analysis	(ppm)	Reporting Limits		(ppm)	Reporting Limits	
TWA	160	3	0.42	100	3	11[c]
TCLP	0.68	0.03	0.22	ND	0.03	>95
			0.42	ND/ND[b]	0.03/0.03	>95/>95
			0.62	ND	0.03	>95

Analyte: Lead	Raw Waste		Additives Ratio[d]	Treated Waste		Percent Reduction
Analysis	(ppm)	Reporting Limits		(ppm)	Reporting Limits	
TWA	15,000	10	0.42	9,000	0.1	15[c]
TCLP	14	0.1	0.22	23	0.1	-100
			0.42	ND/ND[b]	0.1/0.1	>99/>99
			0.62	34	0.1	-293

Table C-2-1. Analytical Results for Purity Waste (continued)

Analyte: Zinc	Raw Waste		Additives Ratio[d]	Treated Waste		Percent Reduction[e]
Analysis	(ppm)	Reporting Limits		(ppm)	Reporting Limits	
TWA	1,000	2	0.42	580	2	18[c]
TCLP	14	0.02	0.22	6	0.02	48
			0.42	0.089/0.074[b]	0.02/0.02	99/99
			0.62	5.9	0.02	32

Analyte: Benzene	Raw Waste		Additives Ratio[d]	Treated Waste		Percent Reduction[e]
Analysis	(ppm)	Reporting Limits		(ppm)	Reporting Limits	
TWA	1.2	0.62	0.42	ND	2.1	>(-148)
TCLP	0.031	0.005	0.22	0.012	0.005	53
			0.42	0.013/0.013[b]	0.005/0.005	40/40
			0.62	0.013	0.005	32

Analyte: Toluene	Raw Waste		Additives Ratio[d]	Treated Waste		Percent Reduction[e]
Analysis	(ppm)	Reporting Limits		(ppm)	Reporting Limits	
TWA	10	0.62	0.42	6.7	2.1	5
TCLP	0.1	0.005	0.22	0.061	0.005	26
			0.42	0.072/0.072[b]	0.005/0.005	-2/-2
			0.62	0.074	0.005	-20

Analyte: Xylene	Raw Waste		Additives Ratio[d]	Treated Waste		Percent Reduction[e]
Analysis	(ppm)	Reporting Limits		(ppm)	Reporting Limits	
TWA	30	0.62	0.42	23	2.1	-9
TCLP	0.011	0.005	0.22	0.087	0.005	4
			0.42	0.094/0.095[b]	0.005/0.005	-21/-23
			0.62	0.097	0.005	-43

Table C-2-1. Analytical Results for Purity Waste (continued)

Analyte: Trichloroethylene	Raw Waste		Additives Ratio[d]	Treated Waste		Percent Reduction[e]
Analysis	(ppm)	Reporting Limits		(ppm)	Reporting Limits	
TWA	8.7	0.62	0.42	4.4	2.1	28
TCLP	0.11	0.005	0.22	0.057	0.005	37
			0.42	0.065/0.065[b]	0.005/0.005	16/17
			0.62	0.067	0.005	1

ND = *Not detected*

a = *Spiked sample recovery not within control limits.*

b = *Duplicate analysis of treated waste sample.*

c = *After adjusting for dilution, percent reduction for metal constituents should be zero.*

d = *The additives ratio is the weight of the additives, excluding water, divided by the weight of the wasted treated.*

e = *Percent Reduction* $\left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$

The additives ratio is the weight of the additives, excluding water, divided by the weight of the waste treated, and equals 0.6.

Based on TCLP analyses, STC's technology yielded reductions in leachate concentrations for two of eleven volatile organics. The results for eight volatile organics were inconclusive due to low concentrations in the raw waste leachate, or inconsistent results for reagent ratios. STC's immobilization technology yielded reductions in leachate concentrations for three of six semivolatile organics; three semivolatiles appeared to be mobilized by the STC process. STC's technology yielded reductions in total waste concentrations for two of four volatile organics. Two volatile organics appeared to show an increase in concentration from the raw waste to the treated waste after accounting for treatment reagent dilution. STC's technology yielded reductions in leachate concentrations for ten of twelve metals.

In conclusion, based on the raw waste and treated waste leachate concentrations as measured by the TCLP and percent reductions obtained through treatment, the STC process appeared to be more effective in stabilizing inorganic than organic constituents in the waste found at the Purity Oil Sales site.

Case Study C-3

Kaiser Steel Corporation

Fontana, California

The Kaiser Steel Corporation (KSC) facility was the site of preliminary treatability testing of STC's immobilization technology under the SITE program. The KSC facility at one time occupied approximately 2,000 acres of land in San Bernadino County, California, 45 miles east of Los Angeles, near the City of Fontana.

KSC opened a fully integrated steel producing, finishing, and fabricating facility in 1942. Operations at the plant included steel production in blast furnaces and basic oxygen furnaces, steel finishing in a hot strip mill, a plate mill, a cold rolling mill and a galvanizing mill, and ancillary facilities such as coke oven batteries. In late 1982, Cuyahoga Wrecking Corporation purchased a portion of the facility for dismantling, consisting of three blast furnaces, seven coke oven batteries, and the by-product plant. The remainder of the plant remained in operation until 1983. In 1984, California Steel Industries, Inc. (CSI) purchased the hot strip mill, plate mill, cold rolling mill, and sheet galvanizing mill and resumed steel finishing.

Throughout KSC's history a variety of wastes have been generated at the site, many of which were placed in a series of on-site disposal areas. The specific areas of interest for the treatability study were the tar pits, the east slag pile, and the gas washer water sludge pits. The three tar pits were located on the northwest side of the site and contained 850,000 cubic feet of waste tar from the coke ovens (listed K087). KSC discontinued use of the tar pits in 1973. Analysis of the tar pits indicated the waste contained leachable naphthalenes and phenols, plus other organic compounds. The east slag pile was one of two slag piles located on the southwest side of the plant. In addition to slag, the east slag pile reportedly received asbestos from plant demolition, oily mill scale, waste oil, oily animal fat sludge, lime-neutralized waste pickle liquor, and blast furnace gas washer water sludge. Analysis of oily animal fat sludge in the slag pile indicated the waste contained leachable nickel and cobalt. The gas washer water sludge area, located in the northeast quadrant, contained three in-ground pits. Analysis indicated the waste contained leachable lead and cadmium.

Generally, concentrated contaminants were present as nonaqueous substances that were predominantly polynuclear aromatic hydrocarbons (PAH). Other hazardous constituents present at the site included benzene, toluene, xylene, styrene, phenols, naphthalene, dibenzofuran, methylene chloride, and chloroform. In addition, metals such as lead, arsenic, cadmium, aluminum, iron, chromium, and zinc were present.

In July 1989, area waste characterization samples from six on-site locations were collected and analyzed by EPA's SITE contractor (PRC) to determine the level of contamination. The areas studied were the tar pit (TP), slag/animal fat (SAF), gas washer water sludge (WS), east slag (ES), slag gas washer sludge (SWS), and by-product (BP) areas. The samples were analyzed by Engineering-Science, Inc., using total waste analysis (TWA), Toxicity Characteristic Leaching Procedure (TCLP), and California Wet Extraction Test (CALWET) procedures.

Table C-3-1 summarizes the results of solidification/stabilization treatability studies on the contaminated soils and sludges from the Kaiser Steel Corporation site. The results are accompanied by the appropriate reporting limits, additive ratios, and where possible the calculated percent reduction. The additives ratio was

Table C-3-1. Analytical Results for KSC Waste

Analyte: Arsenic		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TCLP	SAF	0.033[c]	0.01	0.25	0.002	0.002	92
				0.45	ND/0.008[d]	0.002/0.002	91/65
				0.65	0.007	0.002	65
	ES	0.199	0.01	0.45	0.13	0.002	5
	SWS	0.083	0.01	0.45	0.025	0.002	56
	BP	0.009	0.01	0.45	ND	0.002	68
CALWET	SAF	1.04	0.01	0.45	0.3	0.1	58
	WS	0.009	0.01	0.45	ND	0.1	>(-1,511)
	TP	0.003	0.01	0.45	ND	0.1	>(-4,733)
TWA	SAF	70.7[a]	1.0	0.45	43	1.0	12
	WS	28[a]	1.0	0.45	13	1.0	33
	TP	1.81[a]	1.0	0.45	5[b]	1.0	-301

Analyte: Cadmium		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TCLP	WS	2.3[a]	0.05	0.25	1.5	0.01	18
				0.45	0.87/1.2[d]	0.01/0.01	45/24
				0.65	0.4	0.01	71
	BP	0.012[a]	0.05	0.45	ND	0.01	-21
CALWET	WS	5.3	1.0	0.45	0.7	0.1	81
TWA	WS	143	1.0	0.45	88	1.0	11
	SAF	2.5	1.0	0.45	2.3	1.0	-33
	TP	1.6	1.0	0.45	1.9	1.0	-72

Table C-3-1. Analytical Results for KSC Waste (continued)

Analyte: Chromium		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TCLP	SAF	0.05	0.05	0.25	0.16	0.05	-300
				0.45	ND/ND[d]	0.05/0.05[d]	-45/-45
				0.65	ND	0.05	-65
CALWET	SAF	11.1/ND[e]	5.0/0.05[e]	0.45	16.1/ND[e]	0.5/0.1[e]	79/NC
	WS	ND/0.50[e]	5.0/0.05[e]	0.45	0.9/ND[e]	0.5/0.1[e]	NC/71
	TP	ND/0.11[e]	5.0/0.01[e]	0.45	0.9/ND[e]	0.5/0.1[e]	NC/(-32)
TWA	SAF	459	5.0	0.45	340	5.0	-7
	WS	18.1	5.0	0.45	45	5.0	-261

Analyte: Cobalt		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TCLP	SAF	0.31	0.05	0.25	0.12	0.05	52
				0.45	ND/ND[d]	0.05/0.05	77/77
				0.65	ND	0.05	73
	WS	0.12	0.05	0.25	0.08	0.05	17
				0.45	0.07/ND[d]	0.05/0.05	15/40
				0.65	0.06	0.05	18
CALWET	WS	ND	5.0	0.45	ND	0.5	NC
TWA	SAF	120	5.0	0.45	74	5.0	11
	WS	41.1	5.0	0.45	35	5.0	-23

Table C-3-1. Analytical Results for KSC Waste (continued)

Analyte: Copper		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TCLP	WS	0.11	0.025	0.25	ND	0.03	66
				0.45	ND/0.05[d]	0.03/0.03	60/34
				0.65	ND	0.03	55
	BP	0.048	0.025	0.45	0.03	0.03	9
TWA	SAF	713[a,g]	2.5	0.45	400	3.0	19
	WS	211[a,g]	2.5	0.45	170	3.0	-17
	TP	2[a,f,g]	2.5	0.45	13	3.0	-843

Analyte: Lead		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TCLP	WS	5.3	0.1	0.25	14	0.1	-230
				0.45	4.4/6.6[d]	0.1/0.1	-20/-81
				0.65	1.3	0.1	60
	ES	3.4	0.1	0.45	0.12	0.1	95
	BP	1.4	0.1	0.45	ND	0.1	90
CALWET	WS	541	10	0.45	83	1.0	78
TWA	WS	21,200[a]	10	0.45	11,000	10	25
	SAF	138[a]	10	0.45	150	10	-58
	TP	125[a]	10	0.45	39	10	55

Table C-3-1. Analytical Results for KSC Waste (continued)

Analyte: Nickel		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TCLP	SAF	2.5	0.04	0.25	1.8	0.04	10
				0.45	0.17/0.35[d]	0.04/0.04	90/80
				0.65	ND	0.04	97
CALWET	SAF	18.3	4.0	0.45	1.6	0.4	87
TWA	SAF	51	4.0	0.45	320	4.0	-810
	WS	9.5	4.0	0.45	12	4.0	-83

Analyte: Benzene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	130	0.63	0.45	4.4	0.62	95
TCLP	TP	0.53	0.005	0.25	0.68[h]	0.005	-60
				0.45	0.71/0.59[d,h]	0.005/0.005	-94/-61
				0.65	0.51[h]	0.005	-59
	BP	0.018	0.005	0.45	ND	0.005	60

Table C-3-1. Analytical Results for KSC Waste (continued)

Analyte: Toluene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	60	0.63	0.45	6.4	0.62	85
	WS	0.077	0.005	0.45	ND	0.005	91
	SAF	0.015	0.005	0.45	0.013	0.005	-26
TCLP	TP	0.260[f]	0.005	0.25	0.27[h]	0.005	-30
				0.45	0.30/0.26[d,h]	0.005/0.005	-67/-45
				0.65	0.25[h]	0.005	-59
	WS	0.005[f]	0.005	0.25	ND	0.005	-25
				0.45	ND/ND[d]	0.005/0.005	-45/-45
				0.65	ND	0.005	-65
	SAF	0.003[f,i]	0.005	0.25	ND	0.005	-108
				0.45	ND/ND[d]	0.005/0.005	-142/-142
				0.65	ND	0.005	-175
	ES	0.010[f]	0.005	0.45	ND	0.005	28
	SWS	0.007[f]	0.005	0.45	ND	0.005	-4
	BP	0.013[f]	0.005	0.45	ND	0.005	44

Analyte: Xylene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	44	0.63	0.45	10	0.62	67
	SAF	0.007	0.005	0.45	0.026	0.005	-439
TCLP	TP	0.120	0.005	0.25	0.110	0.005	-15
				0.45	0.12/0.14[d]	0.005/0.005	-45/-69
				0.65	0.14	0.005	-93
	BP	0.007	0.005	0.45	ND	0.005	-4

Table C-3-1. Analytical Results for KSC Waste (continued)

Analyte: Acenaphthylene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[f]
TWA	TP	13,000	760	0.45	1,400[i]	1,500	84
	WS	0.49	0.33	0.45	0.18[i]	0.39	47
TCLP	TP	0.74	0.02	0.25	0.29	0.2	51
				0.45	0.3/0.4[d]	0.15/0.1	41/22
				0.65	0.32	0.2	47

Analyte: Anthracene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[f]
TWA	TP	12,000	760	0.45	1,200[i]	1,500	86
	WS	0.86	0.33	0.45	0.43	0.39	28

Analyte: Dibenzofuran		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[f]
TWA	TP	9,000	760	0.45	1,200[i]	1,500	81
	WS	0.66	0.33	0.45	0.42	0.39	8
TCLP	TP	0.28	0.02	0.25	ND	0.2	>11
				0.45	ND/ND[d]	0.15/0.1	>22/>48
				0.65	0.13	0.1	23

Table C-3-1. Analytical Results for KSC Waste (continued)

Analyte: Fluoranthene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	30,000	760	0.45	3,800	1,500	82
	WS	2.2	0.33	0.45	2.1	0.79	-38
	SAF	0.66[i]	9.5	0.45	ND	25	>(-5,392)
TCLP	TP	0.011[i]	0.02	0.25	ND	0.2	>(-2,172)
				0.45	ND/ND[d]	0.15/0.1	>(-1,877)/(-1,218)
				0.65	ND	0.1	-38

Analyte: Fluorene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	13,000	760	0.45	1,200[i]	1,500	87
	WS	0.14[i]	0.33	0.45	ND	0.39	>(-304)
TCLP	SAF	0.270	0.02	0.25	ND	0.2	>7
				0.45	ND/ND[d]	0.15/0.1	>19/46
				0.65	0.12	0.1	27

Analyte: Phenanthrene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	47,000	760	0.45	6,500	1,500	80
	WS	2.9	0.33	0.45	2.0	0.79	0.0
	SAF	1.4[i]	9.5	0.45	ND	25	>(-2,489)

Table C-3-1. Analytical Results for KSC Waste (continued)

Analyte: 2-Methylnaphthalene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	9,800	760	0.45	1,200[i]	1,500	78
	SAF	3.8[i]	9.5	0.45	ND	25	>(-854)
	WS	1.1	0.33	0.45	0.82	0.79	-8
TCLP	TP	0.55	0.02	0.25	0.25	0.2	43
				0.45	0.26/0.38[d]	0.15/0.1	31/-0.2
				0.65	0.28	0.1	16

Analyte: Napthalene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	42,000	760	0.45	6,000	1,500	79
	SAF	13	9.5	0.45	ND	25	>(-179)
	WS	2.2	0.33	0.45	2.1	0.79	-38
TCLP	TP	9.0	0.02	0.25	3	0.2	58
				0.45	3.1/3.6[d]	0.15/0.1	50/42
				0.65	2.8	0.1	49
	BP	0.32	0.01	0.45	1.3	0.01	-489
	SAF	0.013	0.01	0.25	ND	0.01	>4
				0.45	ND/ND[d]	0.01/0.01	>(-12)/(-12)
				0.65	ND	0.01	>(-27)

Table C-3-1. Analytical Results for KSC Waste (continued)

Analyte: Phenol		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	3,900	760	0.45	ND	1,500	>29
	SAF	2.0[i]	9.5	0.45	ND	25	>(-1,713)
TCLP	TP	16	0.02	0.25	5.8	0.2	55
				0.45	4.7/5.8[d]	0.15/0.1	57/47
				0.65	7.3	0.1	25

Analyte: Pyrene		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	26,000	760	0.45	3,600	1,500	80
	WS	4.7	0.33	0.45	3.1	0.79	4
	SAF	1.1[i]	9.5	0.45	ND	25	>(-3,195)
TCLP	TP	0.008[i]	0.02	0.25	ND	0.2	>(-3,025)
				0.45	ND/ND[d]	0.15/0.1	>(-2,619)/ (-1,713)
				0.65	ND	0.1	>(-1,963)

Analyte: 2,4-Dimethylphenol		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	930	760	0.45	ND	1,500	>(-134)
TCLP	TP	4.4	0.02	0.25	ND	0.2	>94
				0.45	ND/1.2[d]	0.15/0.1	>95/60
				0.65	0.27	0.1	90

Table C-3-1. Analytical Results for KSC Waste (continued)

Analyte: 2-Methylphenol		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	800	760	0.45	ND	1,500	>(-172)
TCLP	TP	5.8	0.02	0.25	1.8	0.2	61
				0.45	1.4/2.0[d]	0.15/0.1	65/50
				0.65	1.8	0.1	49

Analyte: 3- & 4- Methylphenol		Raw Waste			Treated Waste		
Analysis	Sample Location	Concentration (ppm)	Reporting Limits (ppm)	Additives Ratio[k]	Concentration (ppm)	Reporting Limits (ppm)	Percent Reduction[l]
TWA	TP	3,300	760	0.45	ND	1,500	>34
	SAF	6.5[i]	9.5	0.45	ND	25	>(-282)
	WS	0.07[i]	0.33	0.45	ND	0.39	>(-708)
TCLP	TP	23	0.02	0.25	7.7	0.2	58
				0.45	6.0/6.0[d]	0.15/0.1	62/62
				0.65	7.4	0.1	47

ND = Not detected
NC = Not calculable
a = Spiked sample recovery not within control limits.
b = Post digestion spike for furnace AA analysis was out of control limits (85-115%), while sample absorbance was less than 50 percent of spike.
c = Reported value was determined by the method of standard additions.
d = Duplicate analyses of treated waste sample.
e = Total/VI Chromium
f = Analyte was detected in the blank.
g = Duplicate analysis not within control limits.
h = Concentration exceeded the calibration range of GC/MS instrument.
i = Concentration is estimated value (below detection limit).
j = Analytical result calculated from a greater dilution than the primary analysis.
k = The additives ratio is the weight of the additives, excluding water, divided by the weight of the waste treated.

$$l = \text{Percent Reduction} = \left[1 - (1 + \text{Additives Ratio}) \times \frac{\text{Concentration of Treated Waste}}{\text{Concentration of Raw Waste}}\right] \times 100.$$

derived using all types of reagents, surfactants, or cements added during treatment but does not include any added water. Percent reduction was calculated using the following formula:

$$\textit{Percent Reduction} = \left[1 - (1 + \textit{Additives Ratio}) \times \frac{\textit{Concentration of Treated Waste}}{\textit{Concentration of Raw Waste}}\right] \times 100.$$

In cases where a contaminant value was not detected in the treated waste, the reporting limit for the treated waste was used to calculate a minimum value for percent reduction (indicated by a ">"). However, if in the raw waste a contaminant value was not detected, or not analyzed, the percent reduction was not calculable (NC).

The metal that was detected at highest level by TWA in the raw waste was lead. Lead is present at a level of 21,200 ppm in raw waste from the wash-water sludge (WS). Metals were also present at significant levels in raw waste from the SAF area. The levels of metals in the leachate from the raw waste from WS, as indicated by the TCLP results, were exceeded by two of the eight regulated metals (cadmium and lead). This sample also exceeded the CALWET soluble threshold limit concentrations (STLC) for both lead and cadmium and therefore meets the California's hazardous waste criteria.

Base neutral and acid extractable organic compounds, as indicated by the TWA results, were detected in concentrations in excess of 10,000 mg/kg in the raw waste samples from the TP location. Most significant amount of leachable organics were also from the raw waste from the tar pit location with several compounds having concentration greater than 1 mg/L.

Moderate levels of both organics and metals have been detected in raw waste from the SAF area. Arsenic, cadmium, chromium, cobalt, copper, lead, nickel, naphthalenes, and phenols are present at moderate levels in the SAF area. The CALWET test did not indicate that STLCs were exceeded for any of the metals in raw waste from the SAF area.

No pesticides, polychlorinated biphenyls (PCB), or asbestos were detected in any of the raw waste samples. Therefore, these parameters were not analyzed for treatability testing.

The raw waste samples were analyzed for the CALWET list metals. Organics were not analyzed according to the CALWET protocol because no organic compounds were detected in the TWA at concentrations greater than the respective STLCs. All CALWET inorganic concentrations, with the exception of the BP lead and zinc leachate concentrations, were significantly higher than the comparable raw waste TCLP leachate concentrations -- in many cases one or two orders of magnitude greater. However, it should also be noted that the CALWET analyte detection limits were significantly greater than the corresponding TCLP analyte detection limits, and the CALWET method is a more aggressive leach test than TCLP as a result of higher acid concentration, longer leaching time, and greater buffering capacity than TCLP leaching solution.

Based on total waste and TCLP analyses of the raw waste collected from the six areas on July 6, 1989, three specific areas were chosen to test the STC technology at the bench-scale level. The three areas that were used for treatability testing were TP, WS, and SAF. Although wastes from the BP, ES, and SWS areas were not used for detailed treatability testing, one solidified waste mold was cast from each location for subsequent TCLP analysis.

The treatability testing was conducted in two successive stages. The first stage consisted of STC specifying the amount of Soilsorb (its proprietary reagent) estimated to effectively stabilize the waste. In order to develop an "optimum" reagent to waste ratio, STC then cast three sets of molds for each waste: one set at the specified Soilsorb concentration, one set at 50 percent of the specified Soilsorb concentration, and one set at 150 percent of the specified Soilsorb concentration. For example, for the SAF waste, STC specified a Soilsorb concentration of 20 percent of the weight of the waste. In addition to molds cast with this concentration, STC also cast molds of treated waste containing 10 percent and 30 percent Soilsorb by weight

before addition to the waste. After curing, one mold of each Soilsorb concentration was tested by TCLP for each area. One duplicate mold containing the originally specified Soilsorb concentration was also tested.

The second stage of the treatability study was conducted in November 1989 on samples TP, WS, and SAF. TWA, CALWET, Unconfined Compressive Strength (UCS), and permeability tests were made on these samples. TWA and CALWET results are included in Table C-3-1. Results for the UCS and permeability tests are shown in Table C-3-2.

Results from the second-stage treatability study showed moderate to high percent reductions for the metals arsenic, cadmium, chromium, lead, and nickel using CALWET leach criteria; however, arsenic and chromium did not show consistent percent reductions. TWA of organic volatiles showed a moderate percent reduction for xylene and higher percent reductions for benzene and toluene. However, no methods were used to capture and quantify any volatiles that may have been airstripped during treatment.

Semivolatiles report mixed results with respect to percent reductions depending predominantly on initial concentrations of the raw waste and the corresponding reporting limits used in the calculations for non-detected values in the treated waste. In general, however, concentrations of semivolatiles were substantially lowered upon treatment.

Table C-3-2. Summary of Physical Analysis of KSC Waste

Sample	UCS[a] (psi)	Permeability[b] (cm/sec)
TP	203	6.4×10^{-7}
WS	46	1.8×10^{-5}
SAF	247	6.0×10^{-7}

a = Unconfined compressive strength - average of three measurements.

b = average of three measurements

Case Study C-4

Brown Battery Breaking Superfund Site

Reading, Pennsylvania

This case study presents the results of a STC laboratory-scale treatability study performed on soils from the Brown Battery Breaking Superfund site located near the town of Reading, Pennsylvania. STC's analytical and leach test results for lead are shown in Tables C-4-1 and C-4-2. The samples were treated with STC proprietary reagents and allowed to cure for 7 days prior to leachability analysis. Total lead concentrations for the untreated waste ranged from 2,350 ppm to 53,600 ppm. Raw waste Extraction Procedure (EP) leachates contained from 5.6 ppm to 159 ppm lead, whereas post-treatment EP leachates contained 0.24 ppm to 0.29 ppm. Lead concentrations for the CALWET leachates of the raw waste samples ranged from 55 ppm to 679 ppm, while the treated samples contained 0.65 ppm to 4.23 ppm lead. ANS 16.1 Leachate Test results produced less than the detectability limits of 0.2 ppm lead for each of the 5-day leach periods. Untreated sample pH ranged from 7.5 to 7.8, and the treated samples ranged from 9.5 to 11.2.

These results indicate that the STC treatment process did reduce the concentrations of lead in various leachates; however, since the dilution factor was not reported, specific contaminant percent reduction could not be accurately determined.

Table C-4-1. Lead Analyses for Untreated Brown Battery Plant Soils

Sample	TWA (ppm Pb)	EP (ppm Pb)	CALWET (ppm Pb)	pH
1	2,350	5.55	5.5	7.5
2	14,700	52.3	301	7.5
3	53,600	159	679	7.8

Table C-4-2. Lead Analyses for Treated Brown Battery Plant Soils

Sample	EP (ppm Pb)	CALWET (ppm Pb)	ANS 16.1[a] (ppm Pb)	pH
1	0.235	1.82	< 0.2	9.5
2	0.411	4.23	< 0.2	9.8
3	0.290	0.65	< 0.2	11.2

a = Values are for each 5-day leach period.

Case Study C-5

Lion Oil Company

El Dorado, Arkansas

STC organophilic silicates were used to treat over 30,000 cubic yards of refinery sludge from the Lion Oil Refinery in El Dorado, Arkansas. This case study presents the post-treatment verification analytical results from Engineering Research Technology (ERT) laboratory for TCLP leach tests of selected metals and analysis for volatile and semivolatile organics. In addition, solidification results are included for varying sludge-stabilizer compositions.

Table C-5-1 presents the metal analyses for the treated sludge TCLP leachate. All metals shown, with the exception of arsenic and barium, were below the method detection limits. The arsenic level was only slightly above the detection limits at 0.0036 ppm, while the barium concentration was 0.19 ppm. Table C-5-2 presents results for the volatile and semivolatile organic compounds of the treated sludge. Again, all organic compounds analyzed were below the detection limits for the treated wastes; however, concentrations of metals and organic compounds for the raw sludge were not available for this report.

Solidification results for the Lion Oil Refinery sludge are presented in Table C-5-3. Unconfined compressive strengths were measured after 2, 4, and 5 days for varying sludge-stabilizer compositions. The greatest strengths were obtained using approximately 70 to 80 percent sludge by weight in addition to 7 to 11 percent Type 3 cement and 1.4 to 2.4 percent STC proprietary Soilsorb reagents. In addition, kiln dust, natural soil, and backfill material, in quantities varying from 8 to 21 percent, also increased solidification strengths for the treated sludge.

Table C-5-1. Analytical Results of Metal Concentrations from the Lion Oil Refinery Treated Sludge

Analyte	TCLP (ppm)
As	0.004
Ba	0.19
Be	<0.05
Cd	<0.05
Co	<0.05
Cr	<0.20
Hg	<0.003
Ni	<0.15
Pb	<0.15
Sb	<0.30
Se	<0.003
V	<0.05

Table C-5-2. Analytical Results of Volatile and Semivolatile Organic Compounds from the Lion Oil Refinery Treated Sludge

Volatile Organic Compounds	ppm
Benzene	<5
Carbon disulfide	<5
Chlorobenzene	<5
Chloroform	<5
1,2-Dichloroethane	<5
1,4-Dioxane	<10
Ethyl benzene	<5
Ethylene dibromide	<5
Methyl ethyl ketone	<10
Styrene	<5
Toluene	<5
Xylene	<5

Semivolatile Organic Compounds	ppm
Anthracene	<20
Benzo(a)anthracene	<20
Benzo(b)fluoranthene	<20
Benzo(k)fluoranthene	<20
Benzo(a)fluoranthene	<20
Bis(2-ethylhexyl) phthalate	<20
Butyl benzyl phthalate	<20
Chrysene	<20
Dibenzo(a,h)acridine	<100
Dibenzo(a,h)anthracene	<20
Dichlorobenzenes	<20
Diethyl phthalate	<20
7,12-Dimethylbenz(a)anthracene	<20
Dimethyl phthalate	<20
Di(n)butyl phthalate	<20
Di(n)octyl phthalate	<20
Fluoranthene	<20
Indene	<20
Methyl chrysene	<20
1-Methyl chrysene	<20
Naphthalene	<20
Phenanthrene	<20
Pyrene	<20
Pyridine	<20
Quinoline	<100

Table C-5-3. Solidification Results for the Lion Oil Refinery Sludge

Composition (wt.%)	Time (hrs)			
	24	48	72	>72
	Unconfined Compressive Strength (psi)			
SL 81.3 C^3 8.1 KD 8.2 SS 2.4	55	63	>63	118
SL 70.0 C^3 7.6 NS 21.0 SS 2.0	63	>63	>63	135
SL 75.6 C^3 7.6 BF 15.2 SS 1.6	29	33	35	47
SL 73.0 C^3 11.0 BF 14.6 SS 1.4	46	55	>62	>135
SL 73.5 C^3 11.0 BF 14.7 SS 0.8	17	21	23	34
SL 83.3 C^3 8.3 KD 8.4	17	21	22	22
SL 30.0 NS 0.0 C 70.0	>49	NT	NT	NT
SL 33.3 NS 33.3 C 33.3	49	NT	NT	>63
SL 40.0 NS 30.0 C 30.0	52	NT	NT	56
SL 40.0 NS 25.0 C 35.0	52	NT	NT	>56

Table C-5-3. Solidification Results for the Lion Oil Refinery Sludge (continued)

Composition (wt.%)	Time (hrs)			
	24	48	72	>72
	Unconfined Compressive Strength (psi)			
SL 40.0 NS 0.0 C 60.0	49	NT	NT	NT
SL 50.0 NS 0.0 C 50.0	45	NT	NT	NT
SL 46.0 NS 27.0 C 27.0	21	28	NT	NT
SL 40.0 NS 30.0 C 30.0	24-2	42	NT	NT
SL 46.0 NS 27.0 C 27.0	>63	NT	NT	NT
SL 46.0 NS 27.0 C 27.0	>63	NT	NT	NT
SL 50.0 NS 20.0 C 30.0	63	NT	NT	NT
SL 50.0 NS 20.0 C 30.0	63	NT	NT	NT
SL 50.0 KD 50.0 SL 50.0 NS 50.0	<14	<14	<14	F
SL 40.0 FA 60.0	F	F	F	F
SL 35.0 NS 50.0 KD 15.0	<7	<10	<10	<10
SL 30.0 NS 50.0 KD 20.0	7-10	10-14	17-21	NT

Table C-5-3. Solidification Results for the Lion Oil Refinery Sludge (continued)

Composition (wt.%)	Time (hrs)			
	24	48	72	>72
	Unconfined Compressive Strength (psi)			
SL 35.0 NS 50.0 FA 15.0	F	F	F	F
SL 30.0 NS 50.0 FA 20.0	F	F	F	F
SL 52.0 NS 26.0 C 22.0	7-10	NT	NT	NT
SL 50.0 21NS 20.0 C 30.0	3-14	14-17	NT	17-21
SL 50.0 21NS 30.0 C 20.0	14	17	NT	17-21
SL 50.0 17NS 25.0 C 25.0	14-15	15	NT	15-17
SL 55.0 NS 25.0 C 20.0	<10	NT	NT	NT
SL 55.0 NS 20.0 C 25.0	<10	F	F	F
SL 60.0 NS 25.0 C 15.0	<7	F	F	F
SL 60.0 NS 20.0 C 20.0	<7	F	F	F
SL 60.0 NS 15.0 C 25.0	<7	F	F	F
SL 65.0 NS 20.0 C 15.0	<7	F	F	F

Table C-5-3. Solidification Results for the Lion Oil Refinery Sludge (continued)

Composition (wt.%)	Time (hrs)			
	24	48	72	>72
	Unconfined Compressive Strength (psi)			
SL 65.0 NS 20.0 C 15.0	<7	F	F	F
SL 65.0 NS 15.0 C 20.0	<7	F	F	F
SL 71.4 C^3 7.1 NS 21.5	F	F	F	F
SL 76.9 C^3 7.7 BF 15.4	9	11	13	21

BF - Backfilled Soil
C - Type 1 Cement
C^3 - Type 3 Cement
F - Failed upon visual inspection
FA - Fly Ash
KD - Kiln Dust
NS - Natural Soil
NT - Not Tested
SL - Sludge
SS - Soil Sorb

References

U.S. EPA, 1989. Purity Oil Sales Site, Fresno, California: Draft Preliminary Sampling Plan. November.

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